PB85-102507

Nationwide Urban Runoff Program, Winston-Salem, North Carolina: An Evaluation of Street Sweeping as a Runoff Pollution Control

North Carolina Dept. of Natural Resources and
Community Development, Raleigh

Prepared for

Environmental Protection Agency, Washington, DC

Oct 83

U.S. Department of Commerce
National Technical Information Service
NTIS

PB85-102507

Nationwide Urban Runoff Program
Winston-Salem, NC

AN EVALUATION OF STREET SWEEPING AS A RUNOFF POLLUTION CONTROL

OCTOBER 1983

Water Quality

Division of Environmental Management

NORTH CAROLINA DEPARTMENT OF NATURAL RESOURCES AND COMMUNITY DEVELOPMENT

REPORT No. 83-07

REPRODUCED BY
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INFORMATION SERVICE
U.S. DEPARTMENT OF COMMERCE
SPRINGFIELD, VA. 22161

50272-101

REPORT DOCUMENTATION PAGE	1. REPORT NO.	2.	3. Recipient's Accession No. PB85 102507

4. Title and Subtitle
Nationwide Urban Runoff Program, Winston-Salem, N.C., AN EVALUATION OF STREET SWEEPING AS A RUNOFF POLLUTION CONTROL.

5. Report Date
October, 1983

6.

7. Author(s)
(Not identified)

8. Performing Organization Rept. No.

9. Performing Organization Name and Address
N.C. Department of Natural Resources and Community Development
Division of Environmental Management
Raleigh, North Carolina 27611

10. Project/Task/Work Unit No.

11. Contract(C) or Grant(G) No.
(C)
(G) P 004198-01

12. Sponsoring Organization Name and Address
EPA, Office of Water Program Operations
Water Planning Division
401 M Street, SW
Washington, D C 20460

13. Type of Report & Period Covered
Final , Sep, 79-Oct 83

14.

15. Supplementary Notes

16. Abstract (Limit: 200 words)

This is the final report of the Winston-Salem urban runoff study, and focused on two small urban watersheds which together represented 80% of theland use in the Winston-Salem area. One watershed was a central business district, and the other watershed was a residential area. The study was designed to establish an urban stormwater data base which could be used in the NURP assessment, and for urban runoff planning in North Carolina. In addition, the study was designed to evaluate the effectiveness, under real world conditions, of street sweeping implemented as a best management practice (BMP) for the reduction of urban stormwater pollution. The types of samples collected for analysis were street solids accumulation, street cleaning effectivenes-, precipitation, water quality and biological.

17. Document Analysis a. Descriptors

Hydrology
Urban development
Watersheds
Water pollution
Water resources
Sedimentation
Storms
Regional planning
Urban planning
Civil Engineering

b. Identifiers/Open-Ended Terms

Runoff
Streamflow
Stream pollution
Rainfall
Snowmelt
Soil Erosion
Water Quality
Sediments
Sediment Transport
Suspended Solids
Storm Drains
Urbanization
Land use

c. COSATI Field/Group

18. Availability Statement: No restriction on distribution. Available from National Technical. Information Service, Springfield, VA 22161	19. Security Class (This Report) UNCLASSIFIED	21. No. of Pages 229
	20. Security Class (This Page) UNCLASSIFIED	22. Price

(See ANSI-Z39.18) See Instructions on Reverse OPTIONAL FORM 272 (4-77)
(Formerly NTIS-35)
Department of Commerce

NATIONWIDE URBAN RUNOFF PROGRAM
WINSTON – SALEM, NORTH CAROLINA

N. C. Department of Natural Resources and Community Development
Division of Environmental Management
Raleigh, North Carolina 27611

ABSTRACT

This document is the final report of the Winston-Salem/Forsyth County Urban Runoff study conducted by the Water Quality Section of North Carolina's Department of Natural Resources and Community Development/Division of Environmental Management. The study was conducted in conjuction with the U. S. Environmental Protection Agency's Nationwide Urban Runoff Program (NURP), the Forsyth County Environmental Affairs Department, the U. S. Geological Survey, and the Winston-Salem Public Works Department. The Winston-Salem, N. C. NURP was one of 28 such studies conducted in response to a need for characterization of urban runoff and the determination of the effectiveness of a best management practice, street sweeping.

The Winston-Salem/Forsyth County NURP study focused on two small urban watersheds which together represented 80% of the land use in the Winston-Salem area. One watershed was a 22.7 acre central business district (CBD) which discharges urban runoff to Tar Branch, an urban stream that flows into Salem Creek. The other watershed was a 324 acre residential area which was located in the Ardmore subdivision of Winston-Salem.

The major objective of the study was two fold. First, the study was designed to establish an urban stormwater data base which could be used in EPA's NURP assessment and for urban runoff planning in North Carolina. Second, the study was designed to evaluate the effectiveness, under real world conditions, of street sweeping implemented as a best management practice (BMP) for the reduction of urban stormwater pollution.

A twenty-seven month period of sampling established a large and reliable data base from which the effectiveness of street sweeping could be determined. The types of samples collected for analysis were: street solids accumulation, street cleaning effectiveness, precipitation, water quality and biological.

The results of two years of work determined that the pollutant concentration in street solids is high and that street sweeping as a BMP is not effective for water quality goals.

EXECUTIVE SUMMARY

The Winston-Salem urban runoff study was one of twenty-eight Nationwide Urban Runoff Programs (NURP) funded by the United States Environmental Protection Agency to assess the magnitude of urban runoff pollution. Along with quantifying urban runoff generated pollutant loads, each NURP study investigated the ability of a best management practice (BMP) to reduce the urban runoff load. Previous studies (208) had documented high concentrations of metals, nutrients, microbes and some toxic pollutants in urban runoff. Some of these early studies made recommendations for best management practices (BMP's) which would reduce urban runoff.

The Winston-Salem NURP study examined the effectiveness of street sweeping as a best management practice. Two urban land-use types, a residential area and a central business district, were studied under a real world street sweeping program versus the unswept situation. The study confirmed the high runoff associated pollutant concentrations found in the 208 studies. However, the results of the extensive statistical analysis on two years of sweeping and water quality data did not show an improvement in either areas' water quality. Several reasons for the street sweepings ineffectiveness are quite likely. Implications are that the streets, while contributing pollutants to the aquatic environment, may only contribute a small portion of the actual measured pollutant load. Other sources of pollution which would contribute to urban runoff but would not be controllable by street sweeping include atmospheric washout, sidewalk surfaces, roof tops, parking lots and leaky sanitary sewers. In addition, a condition of "armoring" may exist in which large objects on the street block the flow of small particles and their associated pollutants. As the street sweeper removes these large objects, the unswept small pollutants are left unhindered to be washed off the street, thereby decreasing the effects of street sweeping. The armorizing condition is exaggerated by the significantly higher pollutant concentrations associated with street dirt particles less than 45 microns in size.

The study implicated a need to control too many variables in order to make a street sweeping program effective as a best management practice for water quality. Considering the number of street sweepers presently in effect, a few recommendations should still be made pertaining to their use. Primarily, street sweepers should be considered a tool for "urban housekeeping", aesthetics, and not as a water quality BMP, especially in geographical areas with an undefined wet season. Efficiently and effectively using the street sweepers as an urban housekeeping tool would mean:

1. concentrate sweeping efforts one foot from the curb to the curb,
2. concentrate on removing solids that are greater than 45 microns in size, and
3. concentrate on sweeping just prior to a rain event (concentrations peak within one to two days after a sweeping or rain event and thus, the highest removal rates and greatest efficiency would occur just prior to a rain event).

There appears to be two possible solutions to reducing pollution in urban streams. Either solution would be based upon the extent of the perceived problem and economics. One solution, the elimination of the sources entering receiving waters would be the most extreme; reduction the reality. Considering some of the sources, elimination and/or reducing the amount of pollutants capable of entering an aquatic habitat would undoubtedly require controls other than just local ordinances to be effective. However, that is not to say that local concern and policy could not have a beneficial effect.

The second solution would be to treat the urban streams. Waste treatment plants would probably be a cost prohibitive process, however, treatment by detention in wet basins by settling is a viable alternative for certain pollutants, undissolved for example. Detention basins have the advantage over street sweeping in that they can remove more sources of pollutants and also serve in a flood control capacity. The possible disadvantage for an existing urban area would be in acquiring land for constructing the basins which might not be feasible.

The results of the study should provide valuable insight for municipalities presently using a street sweeping program. Second thoughts should be given to the acquisition and use of street sweepers as a best management practice for water quality.

Besides determining the ineffectiveness of street sweeping, the study has provided a substantial urban runoff data base of nutrients and heavy metals along with their instream concentrations and atmospheric deposition rates, from which future policy decisions can be made pertaining to preposed development.

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INTRODUCTION

In 1978 the U. S. EPA determined that additional data was needed to characterize urban runoff. In response to this need, the EPA initiated the Nationwide Urban Runoff Program (NURP). The NURP Program included 28 study sites. Each of the study sites was separate and distinct, however, all were involved with one or more of the following elements:

(1) Characterization of pollutant types
(2) Characterization of pollutant loads
(3) Characterization of pollutant effect on receiving waters
(4) Determining the need for runoff control
(5) Evaluating various stormwater pollution controls termed Best Management Practices (BMP).

The main focus of every project was to develop an accurate data base on which planning decisions about urban stormwater runoff could be made. Additionally, each project evaluated at least one of the five items above. In August 1979, a proposal from the North Carolina Division of Environmental Management (DEM) to study urban runoff in Winston-Salem was accepted for NURP by the U. S. Environmental Protection Agency.

URBAN RUNOFF IN NORTH CAROLINA:

In North Carolina, the industries and overall population are relatively dispersed. Consequently, water pollution effects characteristic of large urban cities in other parts of the nation are not pronounced. In 1970, only 23.9 percent of the State's population lived in designated urbanized areas, in contrast to 58.3 percent nationwide (Hyman, 1974). Likewise, only 37.3 percent of the State's 1970 population of 5,082,059 lived in standard metropolitan statistical areas (SMSA's).

Nationally, 68.5 percent of the population is centered in SMSA locations (Clay, 1975). A SMSA consists of at least one central city having a minimum population of 50,000 and one or more contiguous metropolitan counties. Seven SMSA's are designated in North Carolina: Asheville, Burlington, Charlotte-Gastonia, Fayetteville, Greensboro-Winston-Salem-High Point, Raleigh-Durham, and Wilmington.

The Piedmont, where 54.1 percent of the population is in urban areas, is the most urbanized region in the State. In the Coastal Plain the figure is 38.6 percent and in the Mountains 24.7 percent (Clay, 1975). The Piedmont is also the most populated region, and the trend towards urbanization in this part of the State is increasing (Figure 1).

The manufacturing industries are concentrated in the central and western Piedmont section, although portions of the Coastal Plain are rapidly becoming industrialized. Textiles, furniture, and tobacco products are the main manufacturing categories. The industry of the State is dominated by small plants, often located in small towns or rural areas.

In North Carolina, several studies have been carried out to determine the magnitude of water quality problems associated with urban runoff. Many of these studies were conducted in the urbanized Piedmont Crescent. Colston (1974) monitored runoff from a 1.67 square mile watershed in Durham that was divided into six sub-basins. The Triangle J Region Council of Governments (TJCOG), a designated 208 planning agency, monitored several urban streams in Durham and Raleigh (TJCOG, 1976). The results of both studies were relatively consistent. The Central Business District and other commercial land use areas were found to generate the highest pollutant loadings for most of the pollutant parameters monitored. Significantly high concentrations of nutrients and heavy metals, notably phosphorus and lead, respectively, were observed. Additionally, work conducted by the Division of Environmental Management (DEM) in conjunction with the Land of Sky Regional Council of Governments (LOSCOG) found urban streams in Asheville to be severely biologically degraded (LOSCOG, 1978).

In 1978 sampling was conducted in the Winston-Salem area to examine the water quality of the Central Business District (CBD) and the residential land uses. Data collected during the study demonstrated some obvious urban-related water quality problems. These limited findings were based on a comparison of the observed pollutant concentrations and proposed water quality standards. Distinct differences in pollutant concentrations from the residential areas and the Central Business District (CBD) were observed for several parameters. The 1979 concentrations of most pollutants were higher in the CBD during the period sampled.

OBJECTIVE

The urban section of the North Carolina Water Quality Management Plan identified techniques which would possibly reduce urban runoff pollutants (DEM 1979). These techniques were both structural and non-structural practices. However, the emphasis was placed on street sweeping as a nonstructural control for established urban areas. The major objective of this study was two-fold. First, the study was set up to establish an urban stormwater data base which could be used in the EPA's national NURP assessment and for urban runoff planning in North Carolina. Second, the study was designed to evaluate the effectiveness, under real world conditions, of street sweeping implemented as a BMP for the reduction of urban stormwater pollution.

STUDY DESIGN:

Two urban watersheds, Figure 2, were selected as study sites in the Winston-Salem area. These sites were a 22-acre central business district (CBD) and a 324-acre residential watershed (Ardmore). Data collected on these two sites over the two years of the study included:

(1) Runoff and rainfall water quality data
(2) Dryfall chemical analysis and loading rates
(3) Street surface loading rates
(4) Chemical analysis of street surface dirt
(5) Street sweeper removal efficiency data

The study was designed so that over the two-year period each watershed was studied under an intense sweeping program (five days per week) and under a no sweeping program resulting in the following sweeping schedule for the project:

Ardmore Residential Watershed Swept	CBD Watershed Swept
Fall/80	Summer/80
Spring/81	Winter/81
Summer/81	Fall/81
Winter/82	Spring/82

For the purposes of our study, seasons were; spring = March-May, summer = June-August, fall = September-November and winter = December-February. The above schedules were adhered to as much as possible.

During the no sweeping periods, data continued to be collected and used as control data for the evaluation of the street sweeping program

The effect of street sweeping was assessed in many ways throughout the study. The actual amount of street dirt available and removed by street sweeping was calculated for both the sweeping program as a whole and for the sweeper itself. Pollutant loads removed by the sweeper and the program were obtained by establishing the chemical make-up of the street dirt. Direct comparisons of the storm water quality for swept and unswept seasons were made.

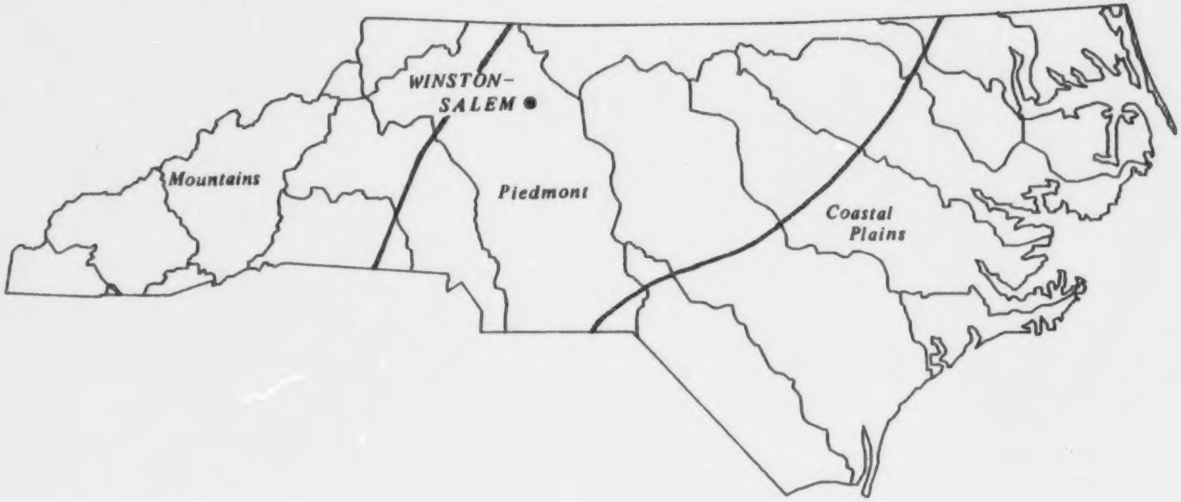

Figure 1

North Carolina Regional and River Basin Boundary Map

LOCATION OF WATERSHEDS IN STUDY

Winston-Salem, N. C.

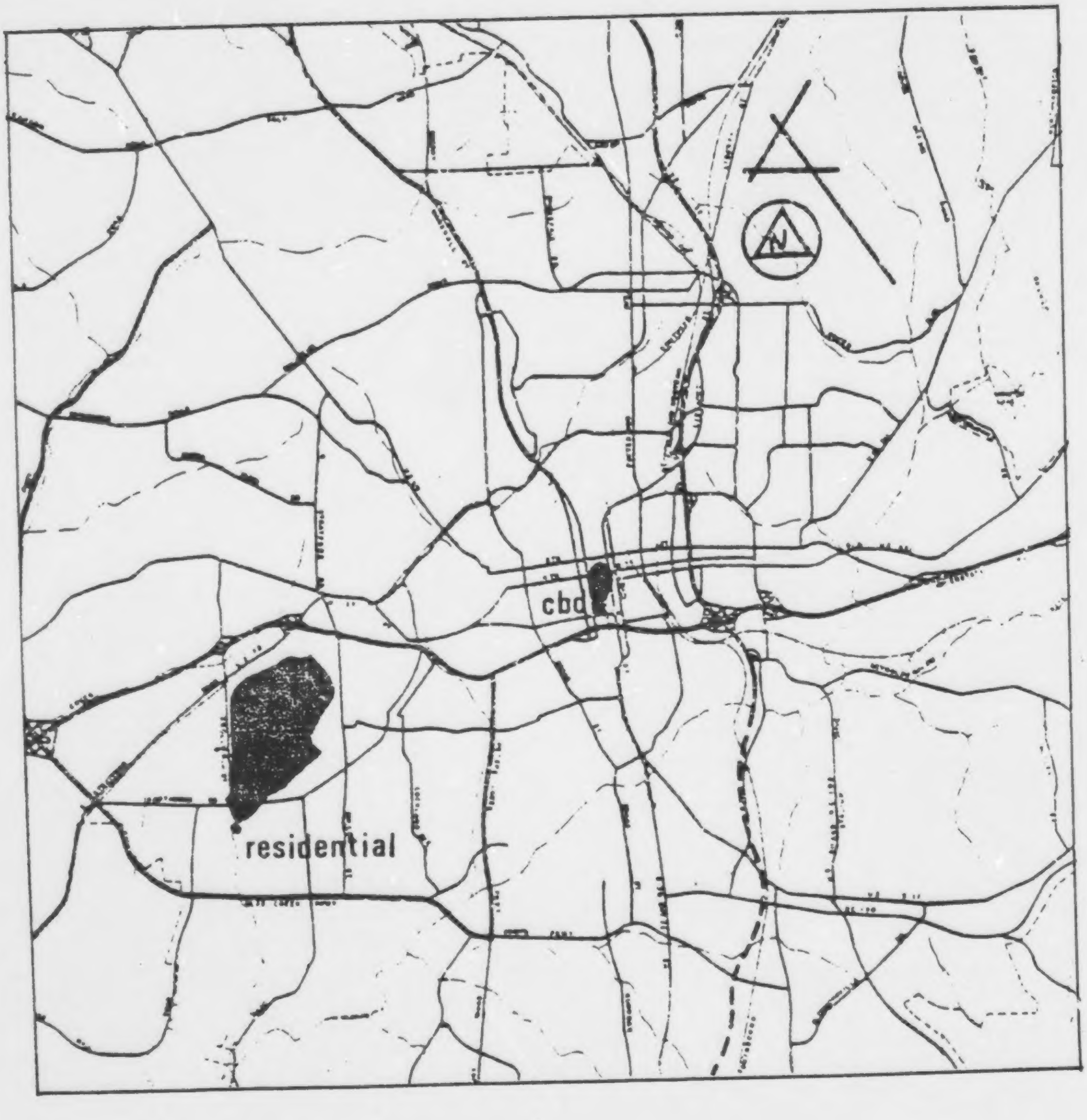

Figure 2

STUDY AREA DESCRIPTION

SELECTION OF STUDY AREAS:

The Winston-Salem area was chosen as the NURP study site because it was designated by DEM as a priority area in the statewide 208 planning process. Winston-Salem is the major urban area in Forsyth County and is located in the central part of the county. The city has a total land area of 61.6 square miles (39,424 acres). Approximately 81% of the land area in Winston-Salem is in residential and related uses. Industry accounts for about 7% of the area. Commercial use accounts for another 7%, and the remaining 5% is in vacant lots.

Several watersheds of various land use characteristics were investigated as to their potential for BMP program testing. Upon consideration of the characteristics of each area and field investigations, two representative watersheds were chosen for study.

Since residential land use accounts for a large percentage of the city, a watershed representative of residential areas in the city was chosen. This watershed, in the Ardmore Community, had been previously studied in a limited manner as part of the 208 monitoring program. Therefore, existing general water quality conditions and watershed characteristics were documented.

Due to the unique problems and high pollutant loadings associated with inner-city, Central Business District (CBD) watersheds, a representative drainage area within the Winston-Salem CBD was chosen for study. Water quality in Tar Branch was monitored during the 208 program, and a general knowledge of associated water quality problems was acquired, thus making it suitable as a study site.

DESCRIPTION OF STUDY AREA

Central Business District (CBD):

Drainage from the 22.7 acre CBD watershed (Figure 3) enters Tar Branch through both open channel and pipe flow. The representative slopes of the catchment and the main channel are 368 ft/mile and 183 ft/mile, respectively. The length of the main channel is 2,068 ft. There are approximately 3.7 miles of lane length or .78 curb miles. Road surfaces in this watershed are asphalt with approximately 93% in fair condition and 7% in poor condition. All roads are curbed and guttered and 100% of the watershed is served with separate sewers. The major soil type of the area is pacolet-urban, which covers approximately six acres (31%) with slopes ranging from 5% to 25%. However, approximately two-thirds of the pervious area are gravel parking lots. These parking lots have a permeability lower than normal undisturbed soil of similar type. The land use of the watershed is entirely commercial with large traffic volumes.

Figure 4 shows the daily average traffic counts (three day average count) at selected locations in the Central Business District. Traffic counts obtained at locations in this watershed range from 1600 to 8959 cars per day.

Residential Watershed:

The residential watershed located in the Ardmore subdivision (Figure 5) has mainly medium density, middle income housing. The neighborhood is well established and has little ongoing construction. The watershed is 324.1 acres in size and drains into Burke Branch below Hawthorne Road. The representative slopes of the catchment and the main channel are 415 ft/mile, and 93 ft/mile, respectively. There are 26.3 miles of lane length or 6.5 curb miles in the watershed which is 98% curbed and guttered. All the roads are asphalt covered. Approximately 3% are in good condition, 95% are in fair condition, and 1% are in poor condition. Twenty-eight percent of the watershed is impervious.

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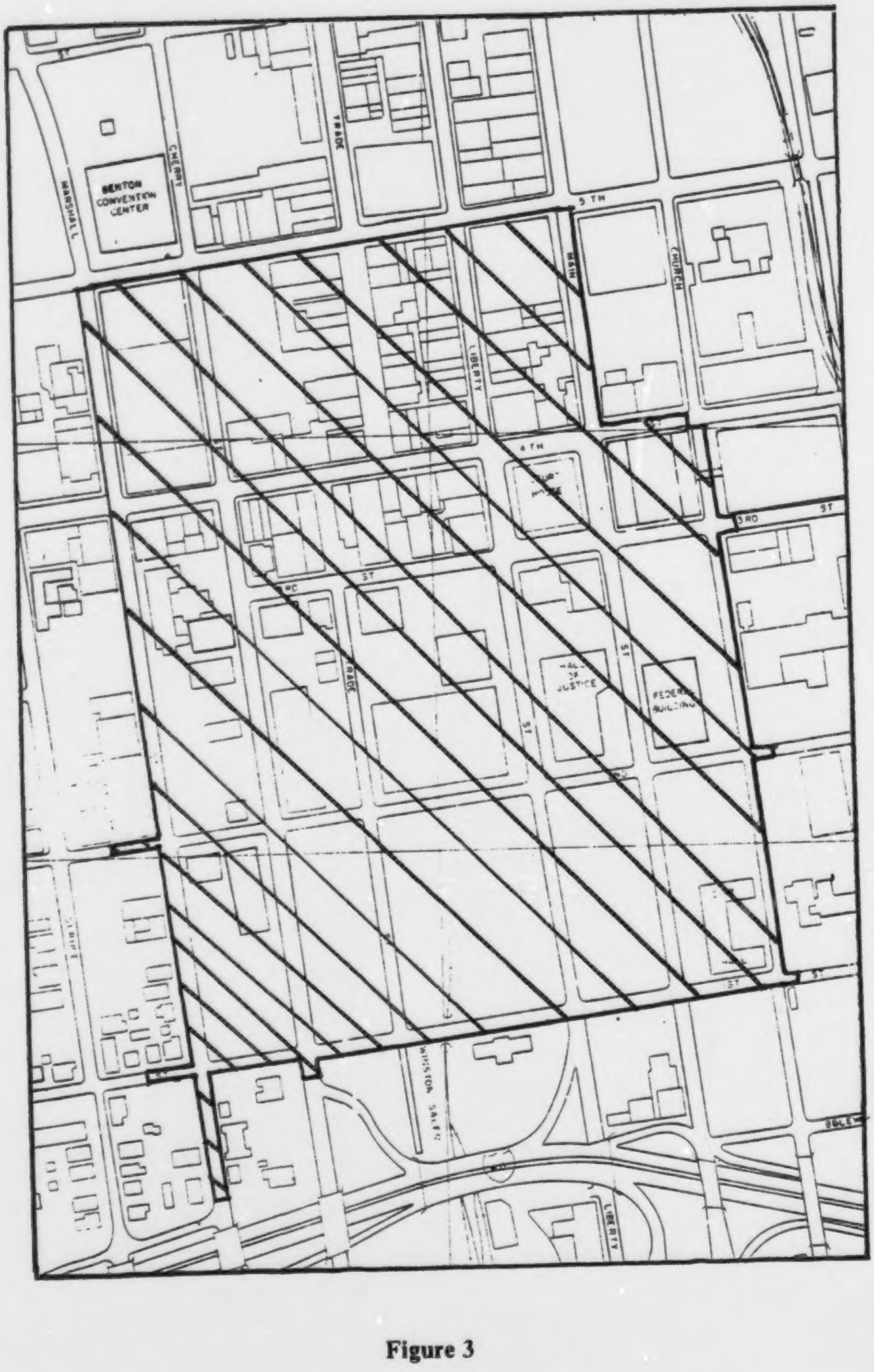

Figure 3

Map of CBD Watershed

Traffic Counts for the Central Business District Watershed

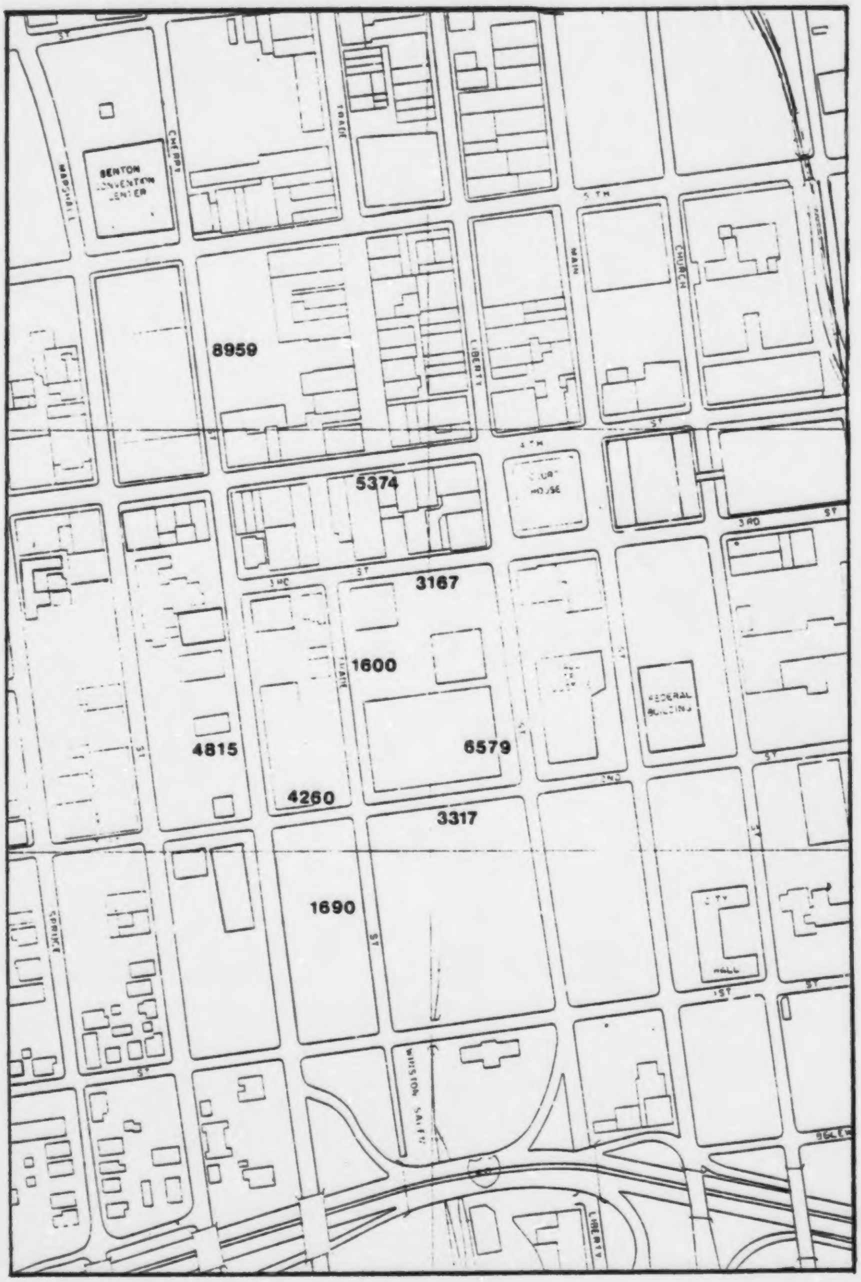

Figure 4

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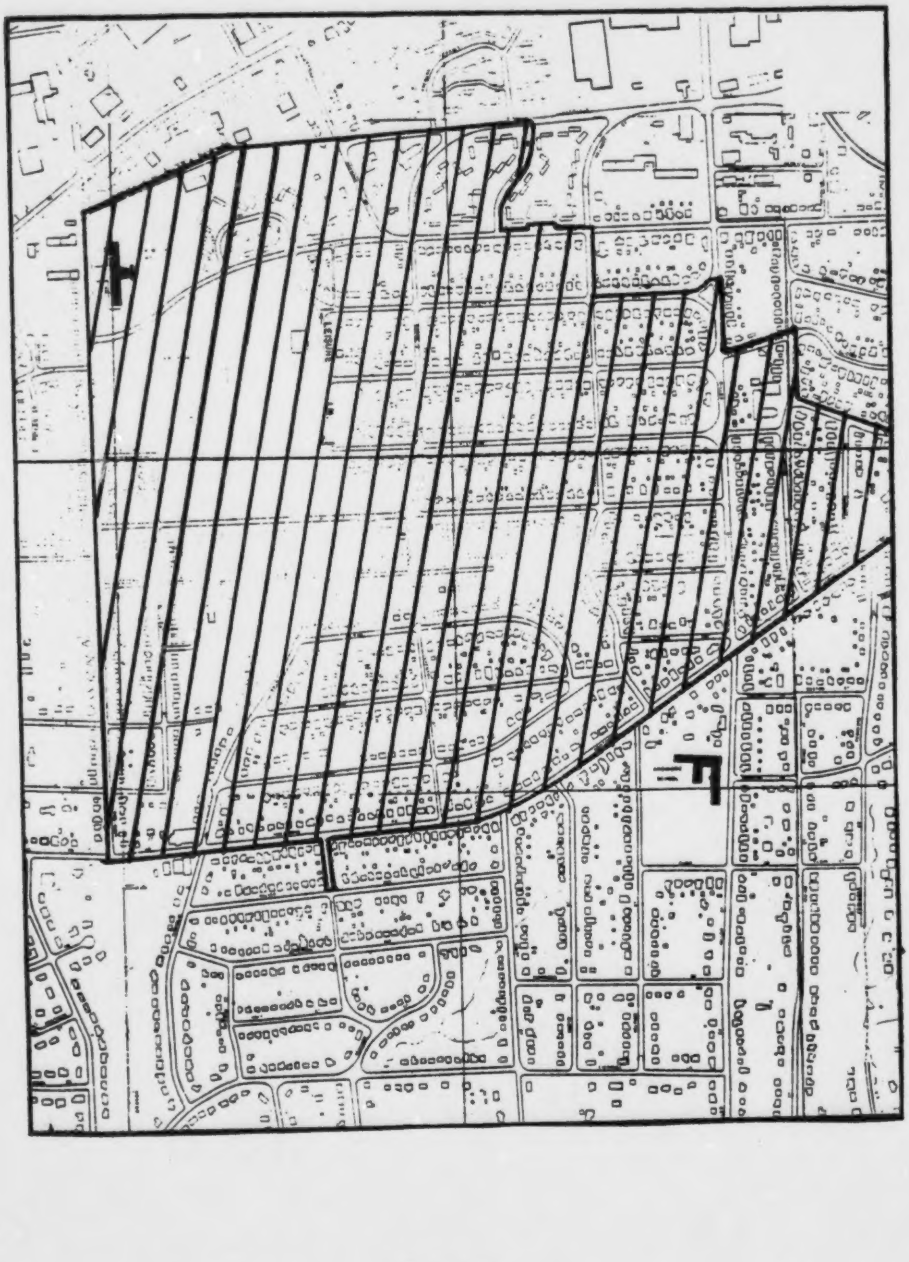

Figure 5

Map of the Ardmore Watershed

The watershed has separate sanitary and storm sewers with approximately 98% of the catchment served by a storm water collection system. The remaining 2% of the runoff flows overland to the drainage channel.

The land use distribution in the Ardmore residential area is as follows:

39.5 acres (12%) Urban Parkland.
6.30 acres (2%) is Light Industrial.
6.85 acres (2%) is Strip Commerical Development.
1.52 acres (1%) is 78 dwelling units per acre residential.
269.94 acres (83%) is 2.5 to 8 dwelling units per acre.

Soils found in the residential watershed include chewacla loam, cecil sandy loams, pacolet fine sandy loam, and pacolet-urban land complex. These soil formations lie in slopes ranging from 6% to 45%.

Figure 6 shows the daily average traffic counts (averaged three days count) at selected locations in the Ardmore watershed. The traffic counts obtained at locations in this watershed range from 65 to 7,790 cars per day with the majority of heavy traffic loadings being on the perimeter.

Drainage:

Drainage patterns in Forsyth County follow three main directions. A very small fraction flows eastward and is received by the Cape Fear River. Approximately 22% of the county's drainage flows north and is contained within the Dan-Roanoke River Basin. Southwestward flow into the Yadkin River accounts for approximately 78% of the drainage.

The Yadkin River is located on the western boundary of the county. The two major tributaries flowing into the Yadkin River from Forsyth County are Abbott's Creek (draining 25.3 square miles in Forsyth County), and Muddy Creek (draining 159.2 square miles in Forsyth County). The Muddy Creek basin drains a major portion of urban Forsyth County, including all of Winston-Salem, portions of the municipalities of Kernersville and Rural Hall, and portions of the unincorporated communities of Walkertown and Clemmons. Muddy Creek tributaries and their drainage areas from north to south include Mill Creek (32.2 square miles), Silas Creek and Little Creek (18.9 square miles), Salem Lake and Salem Creek (69.6 square miles), and the Forsyth County portion of South Fork Creek (36.8 square miles). The Abbott's Creek watershed drains southward directly into the Yadkin River, eastward into the Haw and Deep Rivers, and northeastward into the Dan-Roanoke River Basin. These drainage areas are shown in Figure 7. Both the CBD and the residential study areas are located in the Salem Creek drainage basin. This basin has 43% residential, 9% commercial and 5% other urban land use (Figure 8). Over 50% of the Salem Creek drainage area can therefore be represented by the chosen study areas.

SYNOP RAINFALL ANALYSIS:

A Synoptic analysis was conducted on the long-term rainfall data (1948 to 1975) from the Greensboro/Winston-Salem airport (Medina 1982). This analysis showed a minimum inter-event dry period of 11 hours. The high intensity, short duration storms occurred during the summer while the long duration, low intensity storms occurred during the winter. However, the rainfall data did not show extreme seasonal differences. The mean storm event was shown to be about 0.5 inches and the probability of exceeding this value was 30 percent. The mean inter-event dry period was 3 to 4 days with only a 10% chance of lasting over eight days.

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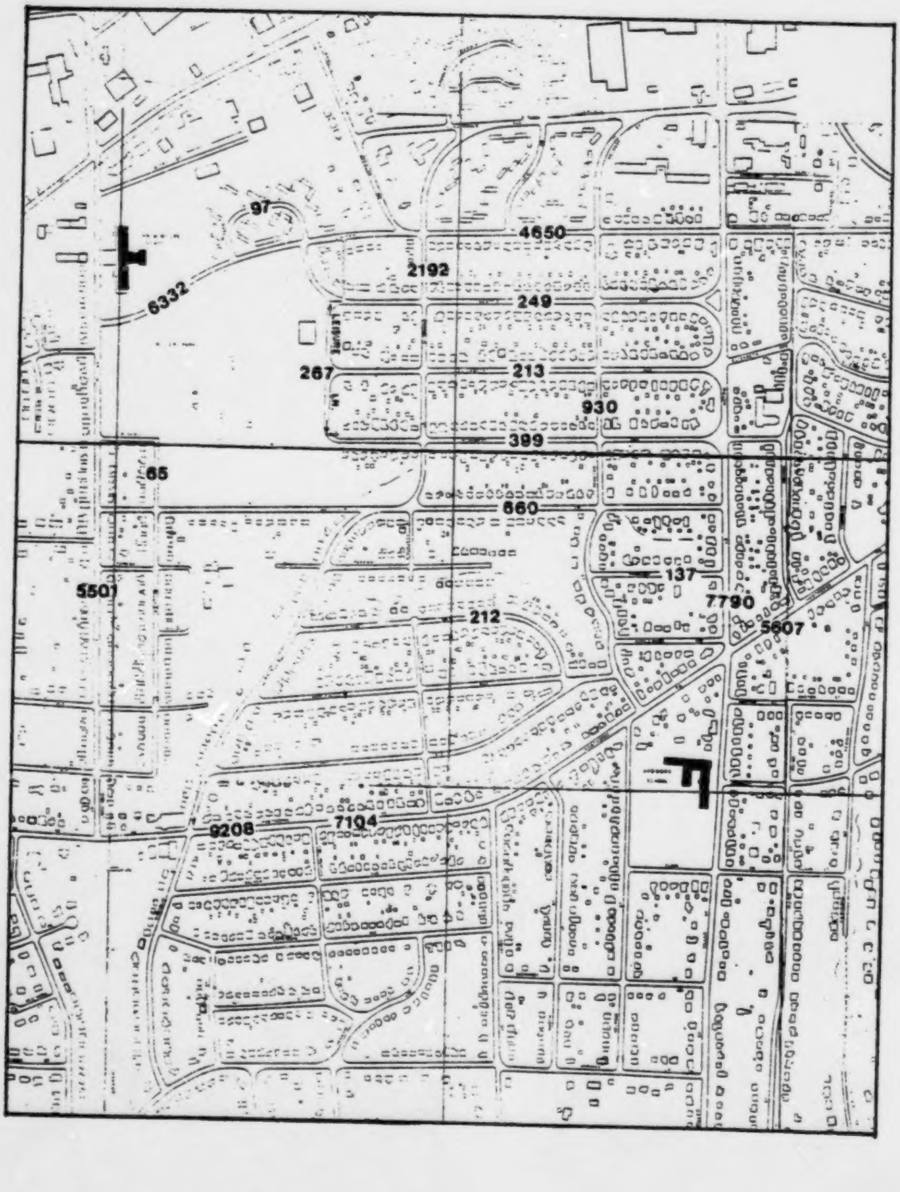
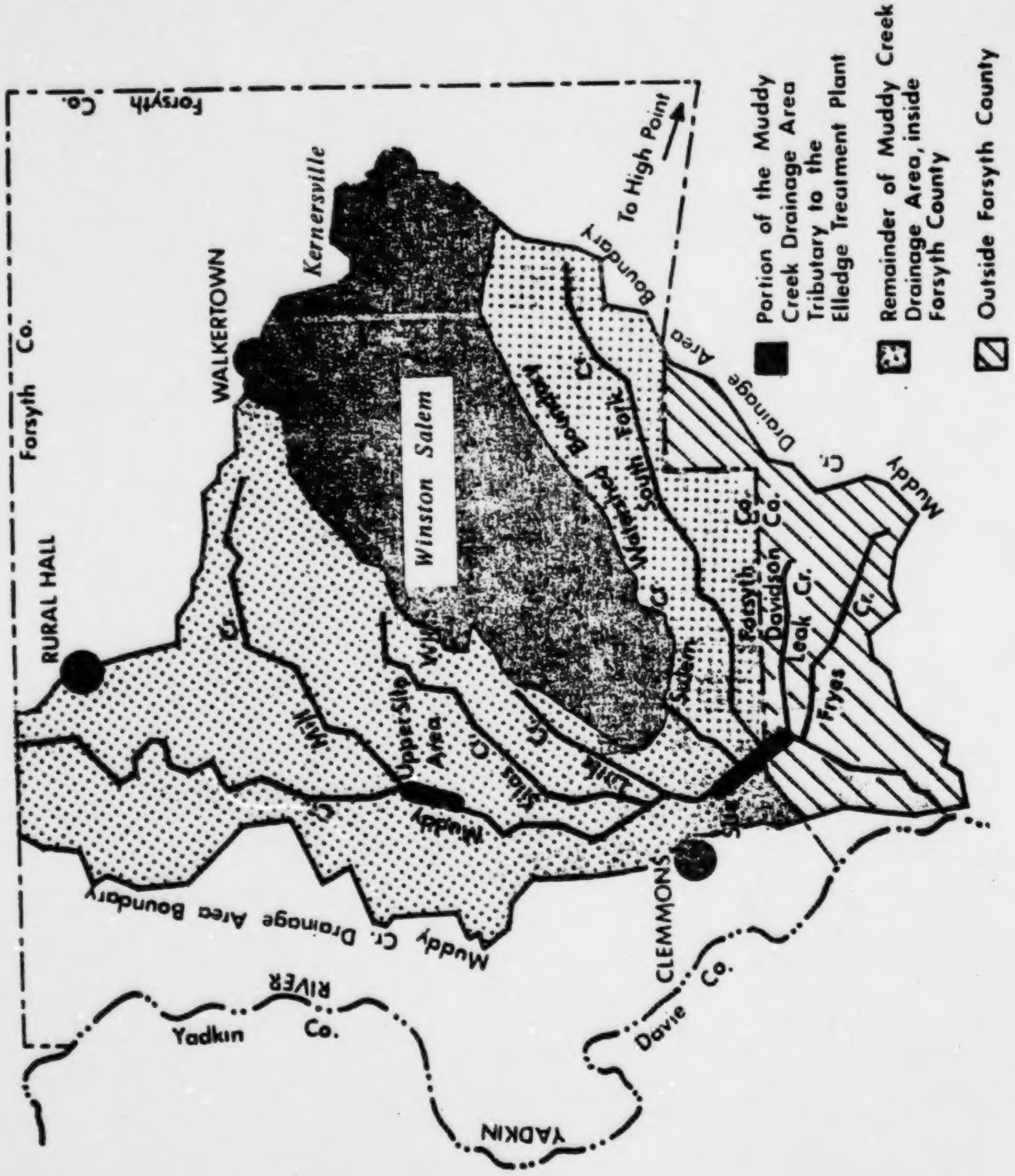


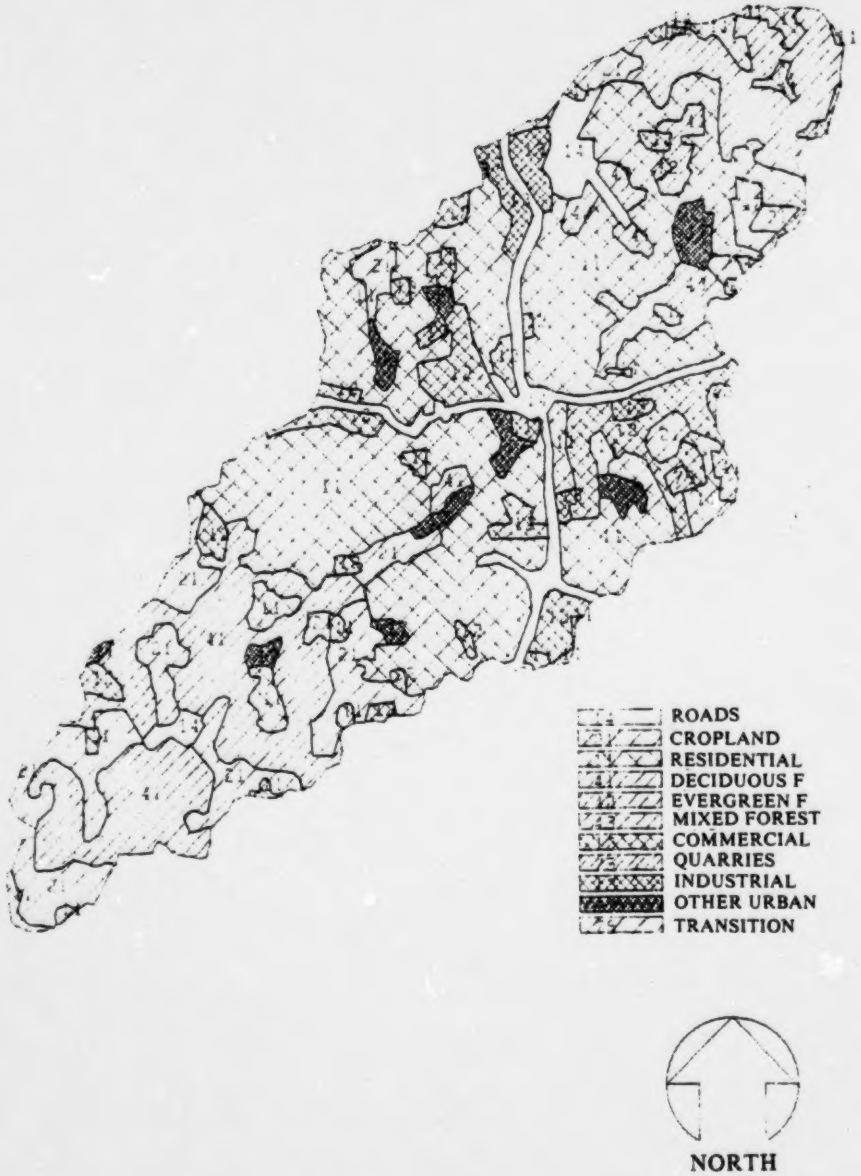
Traffic Counts for the Ardmore Watershed

Figure 6



Forsyth County Drainage Area

Figure 7



SALEM CREEK DRAINAGE AREA

Figure 8

METHODS

ATMOSPHERIC DEPOSITION:

Wetfall Sampling:

Wetfall was collected for analysis using a Aerochemetrics Model 301 sampler at each of three monitoring sites (Fig. 9 & 10). Sample containers were retrieved and replaced with clean containers after every rain event. An event was recorded when enough rain had fallen to initiate runoff from street surfaces within the watershed. Events were separated by a time span of at least six dry hours, i.e., six hours without any detected wetfall.

Samples were analyzed for pH and conductivity in the Environmental Affairs Department (EAD) laboratory, bottled with appropriate preservatives, and forwarded to the DEM laboratory for nutrient and metal analyses.

Dryfall Sampling:

Aerochemetrics Model 301 samplers were also used for dryfall sample collection at all three monitoring stations. Sample containers were retrieved and replaced with clean containers on the first Tuesday of every month. Due to the automated design of the samplers, dryfall and wetfall sampling periods were entirely discrete.

In the EAD laboratory, dryfall samples were removed from their collection containers by sequential rinsing with small volumes of ultra-pure water until a total of one liter of water dilution had been added. These dilute samples were then bottled with appropriate preservatives and forwarded to the DEM laboratory for nutrient and metal analyses.

Meteorological Monitoring:

Rainfall amounts, as well as wind speed and direction, were monitored at each of the three monitoring sites, using Belfort Model 5-780 rain gauges and Weatherthronics Models 2020 and 2030 wind instruments. The Cherry Deck instruments were unobstructed and monitored at a height of approximately seventy (70) feet, while the Second Street instruments were located at ground level (street side) and indicative of only that confined microenvironment (Figure 9).

The Residential meteorological station was sited on the roof of a single story supermarket and was considered to be representative of the residential watershed. Its lower and more biased location did not, however, lend itself to collecting data representing a more regional area (Figure 10).

Total Suspended Particulate Sampling:

Total suspended particulate (SP) concentrations were determined for 24-hour air samples collected at the Cherry Deck site using the federal reference method. The operation, calibration, quality assurance and maintenance of this single air particulates monitor were conducted as an integral part of the ongoing EAD air monitoring network.

BEST MANAGEMENT PRACTICES:

Total lengths of all streets in both study watersheds were labeled using a sequential curb foot numbering system. From this system, twenty-five curb foot numbers were randomly chosen in each watershed. Each random site chosen was inspected and the nearest twelve (12) foot homogeneous loading zone identified and permanently marked to include twelve (12) one foot identical curb to crown strips. These zones were then used as the permanent sampling locations for the entire study.

CBD
Atmospheric Deposition, Meteorlogical and Water Quality Station Sites

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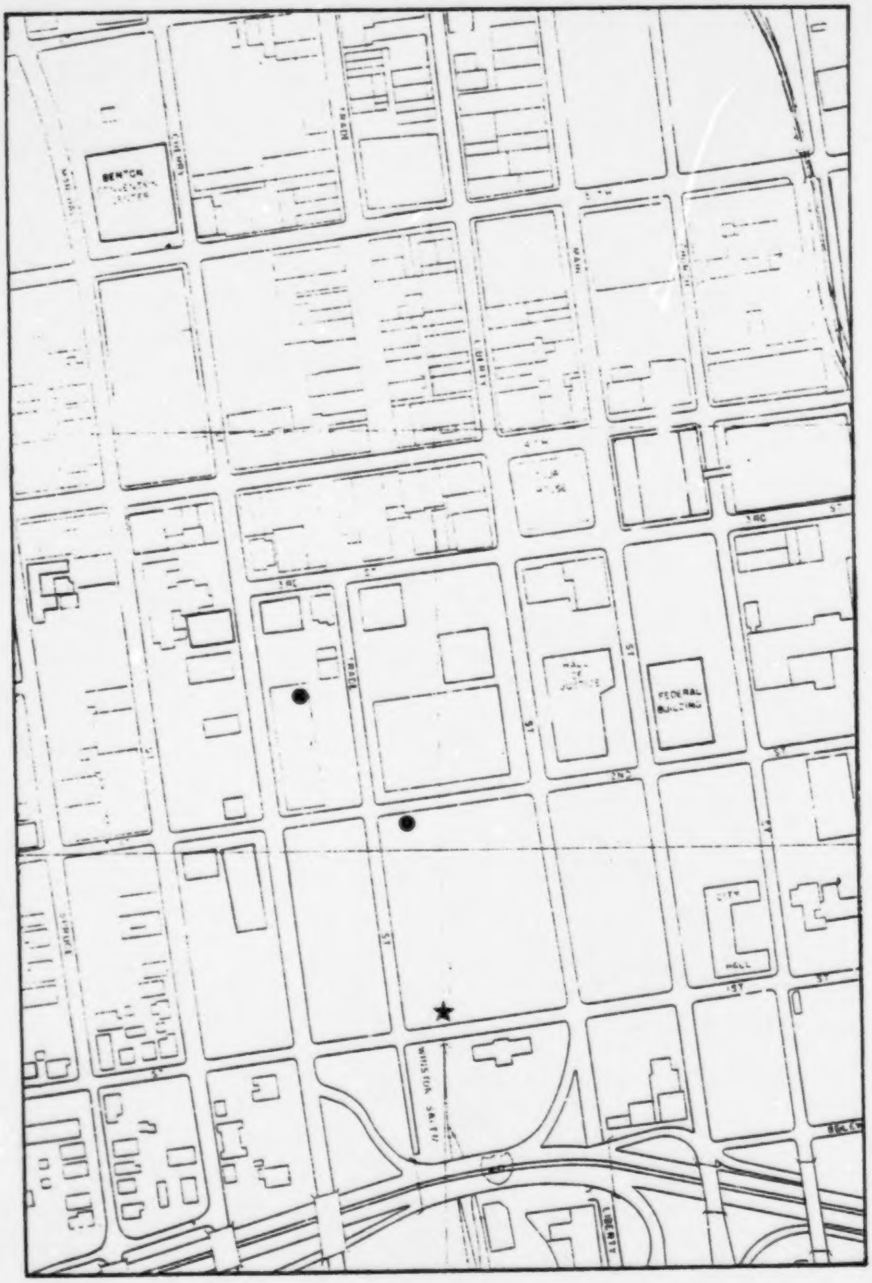

●Atmospheric Deposition and Meteorlogical Site
★Water Quality Station

Figure 9

Residential Monitoring Sites

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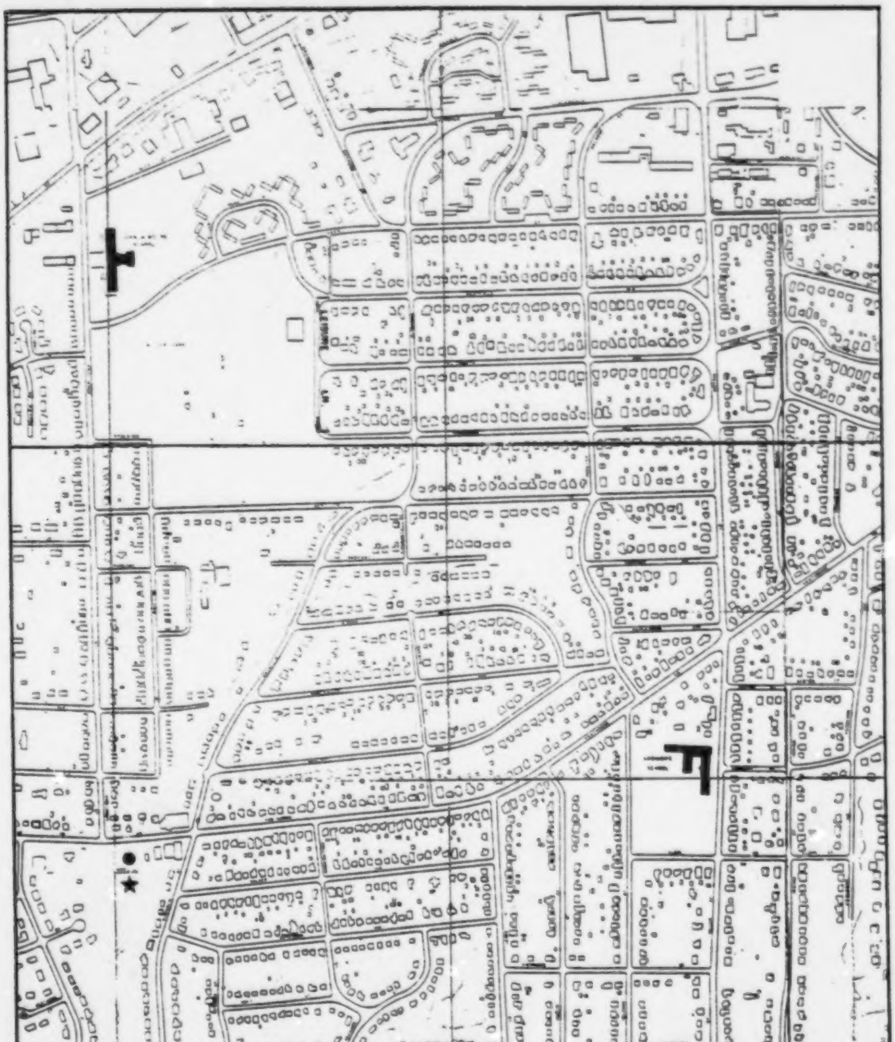

●Atmospheric Deposition Meteorlogical Monitoring Site
★Water Quality Station

Figure 10

All street solids samples were collected with a Torando Model 3000 pro internal vacuum cleaner. One subsample was obtained by making a curb to crown pass over one of the twelve discrete intervals in the homogeneous loading zone. To ensure consistency, a vacuum gauge was used to test the strength of the suction before each sampling.

Accumulation Rate Study:

Accumulation samples were taken during each quarter when sweeping was not being conducted in the study area. This resulted in accumulation samples being collected during the following quarters.

CBD - Spring/80
Fall/80
Spring/81
Summer/81
Winter/82

RES - Summer/80
Winter/81
Fall/81
Fall/81
Spring/82

Each week of the accumulation sampling quarter, one strip from each zone was vacuumed in the watershed being sampled during that quarter (no strip was vacuumed twice in one quarter). Each strip constituted a subsample and all 25 subsamples were collected in the same vacuum making up one accumulation sample.

Following the collection each sample was dried, weighed, sieved and each size fraction was again weighed. Yielding dry weight data for the following particle sizes:

<1/4 inch - litter
3.6 mm (1.4 inch) - 1000 microns
1000 (microns) - 212 microns
212 (microns) - 106 microns
106 (microns) - 45 microns
45 (microns) - 30 microns
30 (microns) - 20 microns
20 (microns) - 5 microns
<5 (microns) -

Pollutant/Particle Size Study

Following the collection and weight analysis of the street solids accumulation samples, the street dirt was held for chemical analysis. After one month (four samples) each of the particle size classes was composited and sent to the DEM laboratory for analysis using sediment analysis techniques.

Across the Street Accumulation:

Two sets of perpendicular streets were chosen in each watershed; one set a representative light traffic area; the other, a high traffic area (Figures 11 & 12). One 10 foot long sidewalk to sidewalk section on each street was marked and labeled in the following manner (Figure 13):

CBD WATERSHED

(1) Strips A & G	(First 4 feet of sidewalk, both sides)
(2) Strips H & I	(Remainder of sidewalks, both sides)
(3) Strips B & F	(One foot from curb, both sides)
(4) Strips C & E	(Between 1 & 5 feet from curb, both sides)
(5) Strip D	(Remainder of street)

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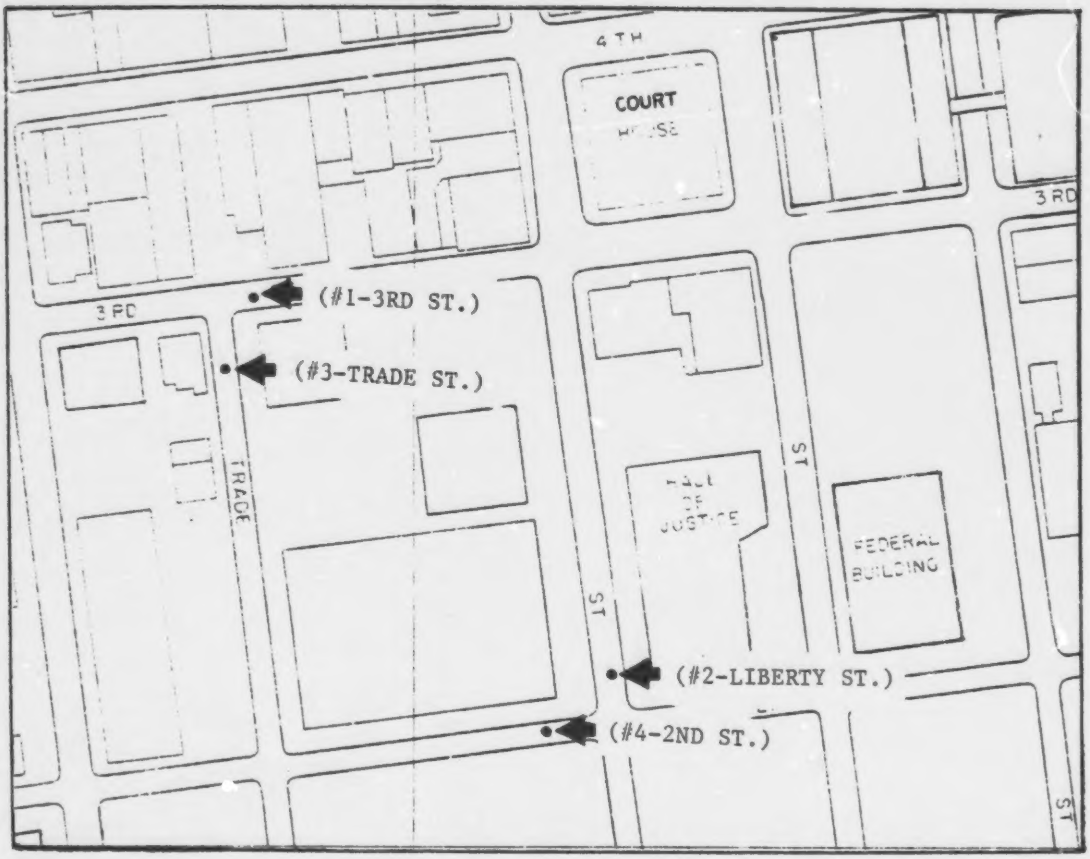


Figure 11.

Location of the across the street sampling sites in the CBD watershed.

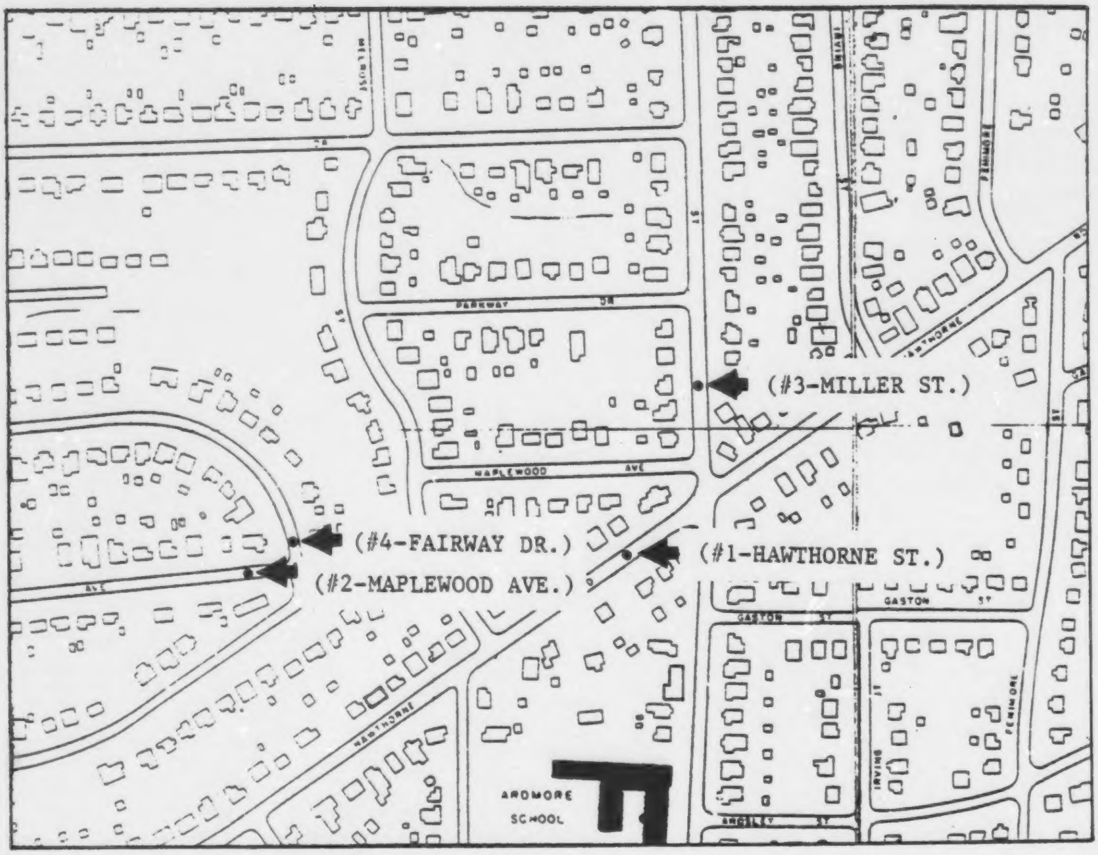


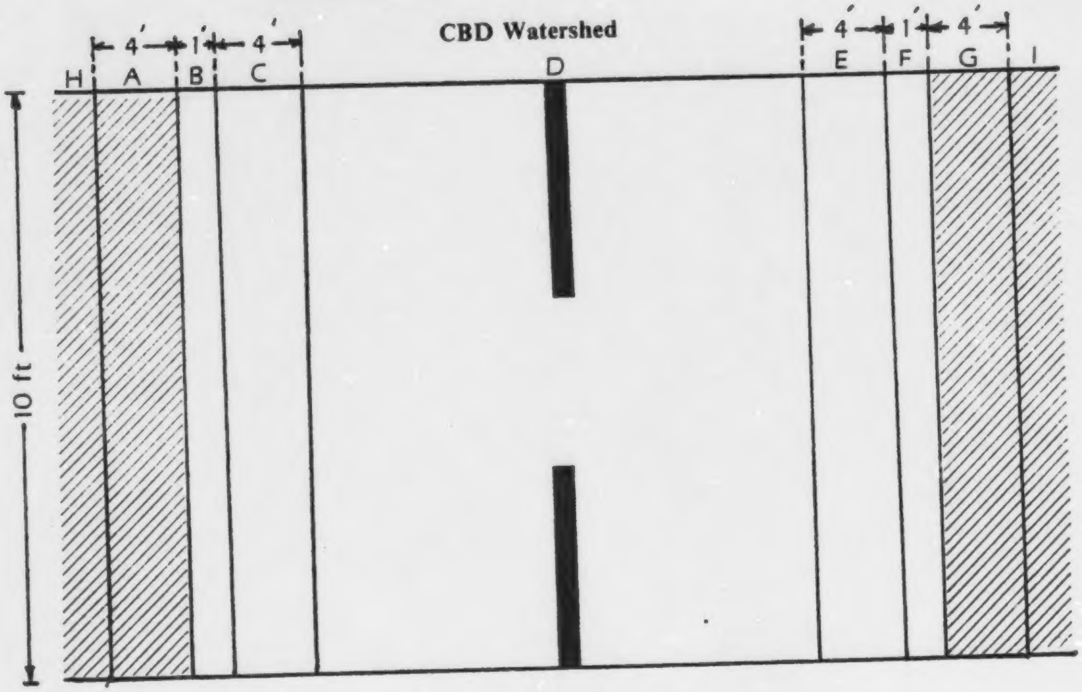
Figure 12.

Location of the across the street sampling sites in the Ardmore Residential watershed.

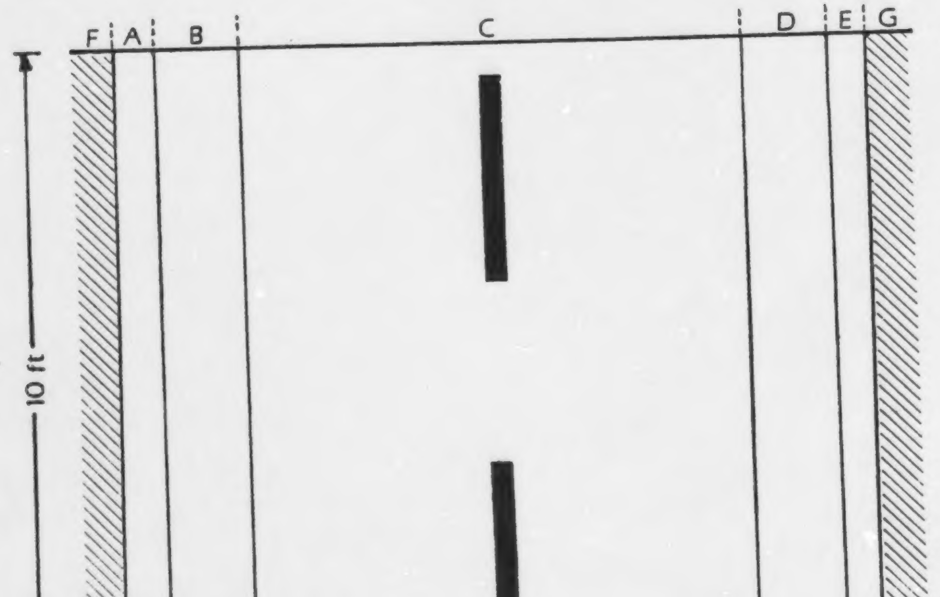
Figure 13.

Sampling strips for the across the street study

CBD Watershed



Residential Watershed



ARDMORE WATERSHED

(1) Strips F & G (Sidewalks, if present)
(2) Strips A & E (one foot from curb, both sides)
(3) Strips B & D (Between feet 1 & 5 from curb, both sides)
(4) Strip C (Rest of street)

Each of the alphabetic strips above were vacuumed individually with a portable backpack vacuum. Similar areas on each side of the street within a section were composited into a single vacuum bag (i.e. strips B and F composed one sample bag in the CBD watershed).

This collection method yielded five bags for each sampling in the CBD and four bags for each residential sampling. After collection, the samples were dried, weighed, sieved and each size fraction reweighed as in the accumulation rate study.

Street Sweeping Practice Performance Determinations:

During the quarters when sweeping was carried out in each watershed, street solid samples were collected weekly to determine the street dirt removal efficiency of the street sweeping program. One sample was taken before street sweeping was conducted in the area and the second after sweeping ended. Care was taken to insure that before and after strips within a zone were well separated and that, if possible, an individual strip was not sampled more than once during a quarter. After collection, the samples (one before and one after) were weighed and sieved in the same manner as the accumulation rate study samples.

WATER QUALITY SAMPLING:

The liquid level and rainfall at each station were measured at 5 minute intervals, by a Lepold Stevens Digital Recorder. Liquid level data was transformed into flow values through the use of a stage discharge rating curve.

Automatic water quality samples were taken by a flow triggered Isco Water Sampler. In the CBD watershed, an Isco flow meter was used to send one pulse to the sampler after allowing a specific volume of water to pass the sampling point. In the residential watershed, the USGS stage recorder sent one pulse to the sampler whenever the flow changed enough to create a change of approximately .25 ft. in stage. The samplers were set to receive from 1 to 999/ pulses (depending on weather predictions) before sampling. The exact stage height which initiated sampling was recorded at the time of sampling by an event marker attached to the USGS stage recorder.

Each time a sample was triggered, four 500 ml bottles were filled (a waste bottle, a nutrient bottle, a metals bottle and a solids bottle). Two samplers were connected in series to allow 14 (four bottle) discrete samples to be taken before the stations needed to be visited. Chemical analysis of the water quality samples was completed by the DEM laboratory according to standard methods for the analysis of water and wastewater (APHA, 1980).

The discrete sampling required the development of a method for obtaining storm loads and event mean concentrations. The method consisted of linearly interpolating between the actually measured concentration values and calculating a change in concentration per 5 minute interval (ΔC). Each five minute increment between the actually measured points was assigned a concentration value by:

$$Ci = A + (N)\Delta C$$

where A= The beginning concentration value
N= The number of 5 minute values between A and the unit value to be calculated
ΔC= Change in concentration per 5 minutes between the two actually measured concentration values.
Ci= Unit concentration value

Unit load values in lbs/day were than calculated by multiplying the flow unit values by the concentration values and the appropriate conversion factors. Total storm load in pounds was then obtained by:

$$\sum_{i=1}^{n} [\ \tfrac{1}{2}\ (L(i+1))-L(i)]\ \ (5/1440)$$

Where Li=unit load in pounds/day
N= number unit load values

Following each storm event, the stage, rainfall, and pollutant data were reduced to yield storm volumes, intensity, loads and event mean concentrations.

BIOLOGICAL STUDY:

Benthic Macroinvertebrates:

All benthic macroinvertebrate samples were collected by the "kick" method. A net was positioned upright on the stream bed, while an upstream area of one square meter was physically disrupted. Duplicate samples were collected at each site. All samples were preserved in ethanol and returned to the laboratory for processing.

Bioassay:

During the months of June, 1981, through March, 1982, a series of urban runoff bioassays were performed. These tests used *Daphnia pulex* as a test organism to measure acute toxicities in the urban runoff components. The urban runoff tests were conducted on both Burk Branch (the residential receiving water) and Tar Branch (the CBD receiving water).

Tests consisted of five to seven concentrations of runoff as well as a control, each concentration was done in replicate. At least ten *Daphnia pulex* (0-3 days old) were transferred under water in 10 ml of dilution water to each test vessel. Mortality was recorded at 24 and 48 hours.

RESULTS

ATMOSPHERIC DEPOSITION:

Both wetfall and dryfall samples were analyzed for both nutrient and metallic pollutant constituents, including ammonia, total kjeldahl nitrogen, nitrates/nitrites, total phosphorus, copper, lead, zinc, mercury, cadimum, cobalt, chromium, manganese and nickel. While all of the four analyzed nutrients were detectable during the two years of the study, only four of the analyzed metals were ever present in amounts above the mimimum detectable limit (mdl): copper, zinc, lead and mercury. The mdl's are <40, <50, <100, <.5 respectively. Nutrient pollutants were found most often in association with the wetfall samples, while metals were observed most frequently in the dryfall samples.

Wetfall ammonia was found in similar quantities at each monitoring site. Likewise, dryfall ammonia was constant at each site. Wetfall values, when compared to dryfall, were much higher, possibly due to the highly water soluble, gaseous nature of ammonia. The pollutant seemed to occur in an areawide pattern, with little effect from local (watershed specific) influence. The highest amounts of ammonia were measured during the summer months. Total kjeldahl nitrogen (TKN) appeared in similar amounts at all monitoring sites, and in both wetfall and dryfall. Wetfall values correlated significantly at each site, indicating an areawide pattern of TKN occurrence, while dryfall amounts appeared to show no relationship to each other. Summer wetfall values were slightly higher than other seasonal amounts. Linear correlations of other monitored nitrogenous pollutants with TKN values, strongly illustrated their native interrelationships.

The amounts of nitrate/nitrite (NO_3/NO_2) measured at each of the CBD monitors were similar, but dryfall amounts in that watershed were higher than at the residential site. Automotive input of nitrogen oxides was thought to influence this difference. Microanalysis of high volume air sampler filters supported this theory. Wetfall amounts of the pollutant were higher than dryfall amounts, probably due to the gaseous nature of the pollutant. The appearance of NO_3/NO_2 was fairly consistent throughout the area during every season of the year.

Total phosphorus (TP) was detected in almost all dryfall samples, while it was measured in only 7% of the wetfall events. No differences were found between the two watersheds in their dryfall TP amounts. Streetside levels, however, were marginally higher than those at the Cherry Deck. The unpaved parking areas immediately adjacent to the monitoring sites are thought to provide this influence. Seasonal comparisons seemed to indicate a greater distribution of TP in the CBD over the RES watershed, although this was not supported statistically.

No differences were noted in copper amounts at any of the three monitoring sites between wet and dry deposition. Dryfall samples in the RES watershed, however, never contained detectable quantities of the metal. Linear comparisons of the dryfall copper values were significant within the CBD. No specific seasonal relationships were noted for wetfall copper.

Dryfall amounts of zinc were significantly higher in the CBD watershed than in the RES. Furthermore, levels at the Second Street site were higher than those at the Cherry Deck, indicating a probable influence from local traffic. Zinc was detected in every dryfall sample, while being measured in only 18% of the monthly rainfall composites. A strong linear correlation was indicated between lead and zinc deposition, again suggesting a traffic related input. Seasonal comparisons suggested the possibility of one biased sample from the Second Street dryfall monitor.

As was the case with zinc, lead was detected much more frequently in dryfall samples than in wetfall samples. No differences were established between dry and wet deposition because there were too few paired samples available for comparison. Streetside levels of the metal were significantly higher than amounts at either of the other sites. No correlation was found between the two CBD monitors. Seasonal comparisons displayed the predominance of dryfall lead amounts in the CBD over the residential watershed, at the Second Street site over the Cherry Deck, particularly in the fall and winter. Lead levels appear to be strongly influenced by traffic.

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Mercury was detected in relatively few samples, as compared to the other detected pollutants. It appeared more often in dryfall samples than in wetfall, and slightly more often in the CBD than the RES. Dry mercury values were higher at the Cherry Deck site than at the Second Street site, and were significant when correlated. Seasonal comparisons demonstrated the considerable disparity between the CBD and the RES levels.

Mean pH values were comparable at the three monitoring locations and individual rain event pH values correlated significantly. The mean pH levels of 3.74 to 3.82 were below the 5.6 level indicative of "pure" rainfall. Weighted averages, using rainfall volume, were not appreciably different than the unweighted means. No significance was found when wetfall sulfates and pH were correlated. Analysis of sulfate content was undertaken late in the project, resulting in only a few data points for comparision purposes.

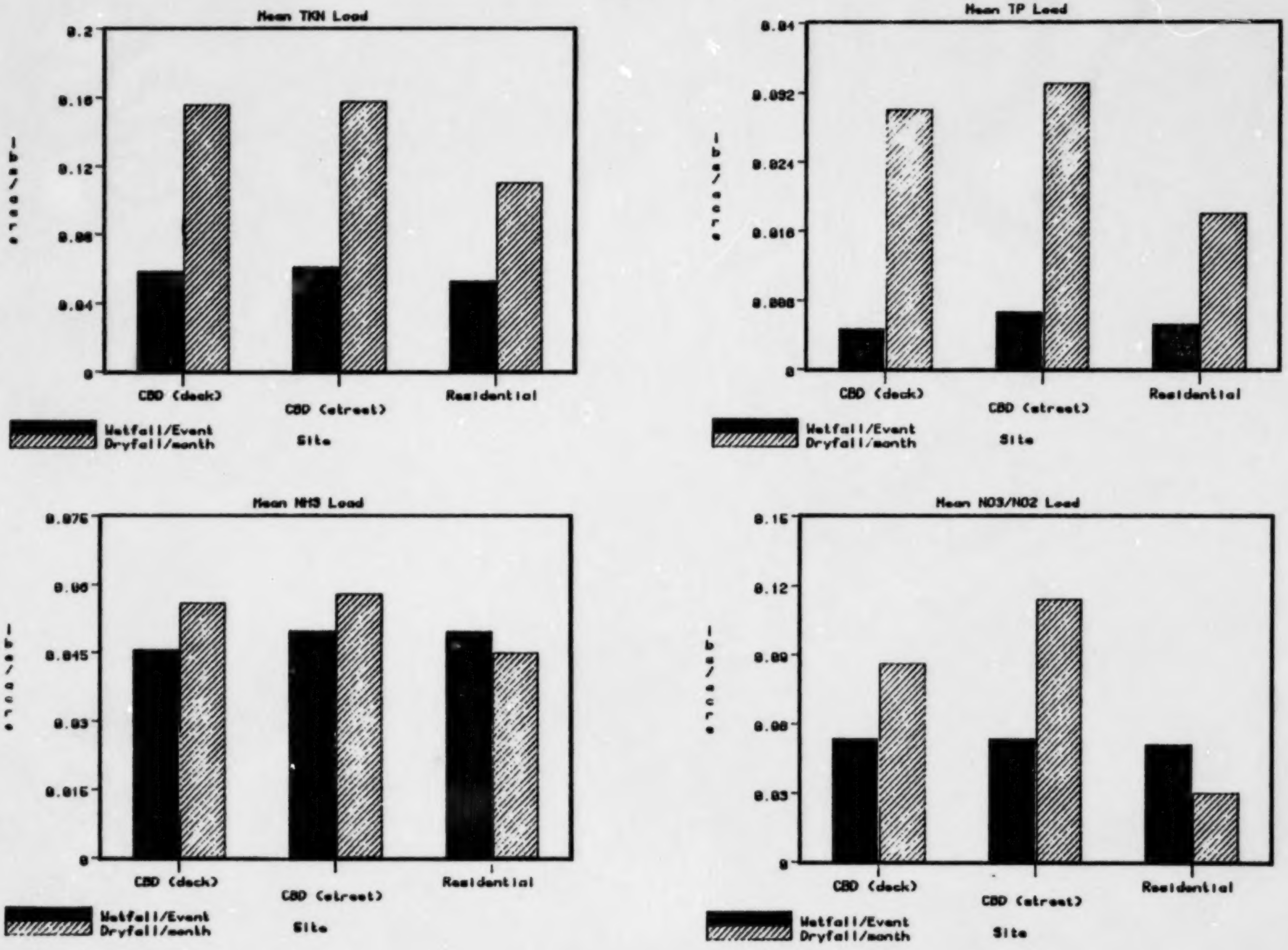
Analysis of high volume air sampler filters indicated that traffic on unpaved surfaces seemed to be the primary contributor of particles to suspended particulate concentrations. Large particle sizes suggested that emission sources of mineral materials were located within a few hundred feet of the sampling site. Mineral content and seasons of the year were related, with higher values occurring during dryer and hotter times of the year.

Wind roses indicated that in the few hours immediately preceding a storm event, winds are, in general, southerly, regardless of the time of year. On dry days, the wind was observed from numerous directions, and reflected historical measurements.

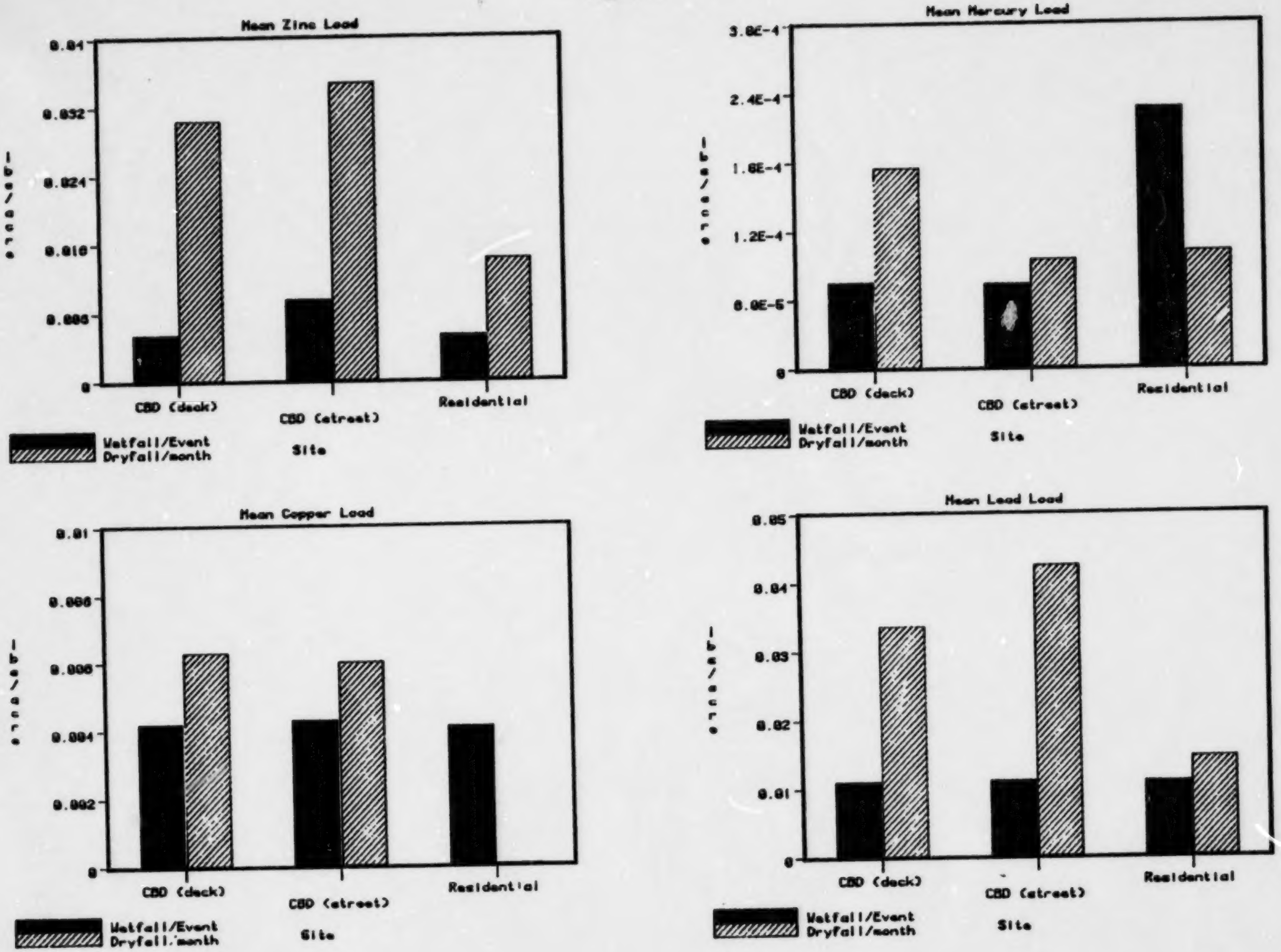
In general, wetfall pollutant deposition was areawide in nature. Dryfall, however, appeared to be influenced by local sources and can vary significantly within short distances. For certain pollutants higher dryfall concentrations were observed at the street side location. This most likely occurs because of reentrainment of particles by automobiles.

Figures 14 and 15 show the average nutrient and metal concentrations at each site per rain event for the wetfall and per month for the dryfall. Using this information in conjuction with the synoptic rainfall analysis and physical watershed characteristics, estimates were made on the average contribution of atmospheric deposition to the average runoff event (Table 1).

Wetfall/Dryfall Loads
Figure 14



Wetfall/Dryfall Loads
Figure 15



Atmospheric Deposition
Input Into An Average Runoff Event

	Wetfall	Dryfall			
	Mean Event	Street Surface Load (lbs.)		Load Deposited on Nonstreet Surfaces (lbs.)	
Parameter	Load (lbs.)	72 hrs.	192 hrs.	72 hrs.	192 hrs.
		DECK			
CU	.0042	.00335	.0089	.0108.	.0287
ZN	.0054	.016	.0429	.0518	.1382
PB	.011	.0179	.0476	.0575	.1532
HG	7.5×10^{-5}	.000093	.0003	.0003	.0008
NH_3	.0456	.0297	.0790	.0957	.2552
TKN	.0585	.0828	.2209	.2666	.7110
NO_3/NO_2	.0534	.04566	.1218	.1469	.3919
TP	.0047	.0159	.0425	.0513	.1367
		RES.			
CU	.0041	—	—	—	—
ZN	.0052	.0533	.1421	.3973	1.0596
PB	.0109	.0545	.14531	.4064	1.0836
HG	22.7×10^{-5}	.0004	.0010	.0028	.0076
NH_3	.0495	.1702	.4538	1.269	3.384
TKN	.0526	.4159	1.1093	3.102	8.2726
NO_3/NO_2	.0510	.1134	.3025	0.846	2.2561
TP	.0052	.0680	.1815	.5076	1.3537

TABLE 1

STREET SOLIDS ACCUMULATION:

The spatial distribution of solids on street surfaces and any relationship which exists between the amount of solids on the street and the amount of time that the solids have been accumulating is important in managing a street sweeping program designed to improve water quality.

Accumulation Rates:

The average accumulation rate of total street solids was 393 pounds per curb-mile per day for the CBD watershed and 281 pounds per curb-mile per day for the residential watershed. Accumulation rate statistics for each particle size class in each watershed are contained in Table 2. The standard deviation statistics in Table 2 show that the data collected was highly variable and, therefore, no significant differences could be detected between watersheds for the accumulation rates of any particle size class or total weight.

Seasonal comparisons were completed using the statistical analysis system (SAS) Duncan procedure (Helwig & Council 1979). It showed that in the CBD watershed all seasons were statistically similar for all particle size classes and total weight. In the Ardmore watershed, however, for particle size classes greater than 30 microns the winter season had a significantly higher average accumulation rate than the summer or fall. This can be attributed to leaf fall in the residential area and while it would be expected that high accumulation rates would also occur in the fall, this was not shown because accumulation sampling during the fall season had to be suspended after leaf fall began. The early winter season was affected by any late leaf fall and therefore, had higher accumulation rates.

Accumulation rate curves were plotted for both watersheds (Figure 16). The curves show only a slight rise in the accumulation after one to two days. This indicates a quick leveling off of the rate at which solids accumulate, therefore the average accumulation in pounds per curb mile should be obtained from the graphs and not calculated from the average rate.

TABLE 2

SOLIDS ACCUMULATION STATISTICS

FRACTIONS 1 - 9 ARE <50, 5-200, 20-300, 30-450, 45-1060,
106-2120, 212-10000, 1000-1/4N AND >1/4N RESPECTIVELY
VALUES OF ACCUMULATION IN POUNDS/CURB-MILE PER DAY

CENTRAL BUSINESS DISTRICT

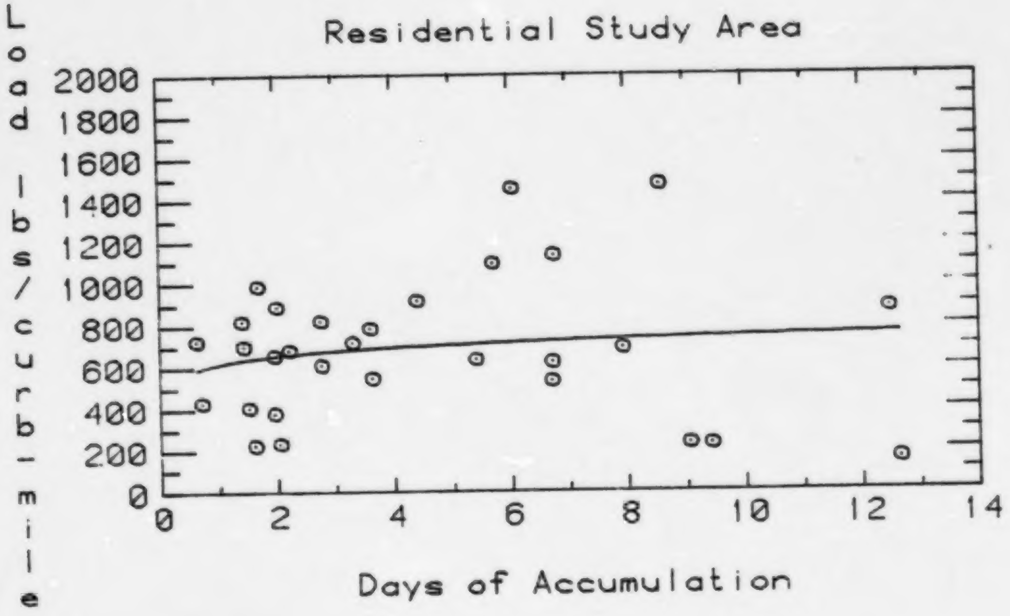
Variable	N	Maximum Value	Mimimum Value	Mean	Standard Deviation
FRAC-1	31	0.22	0.00	0.01	0.04
FRAC-2	31	4.79	0.03	0.50	0.89
FRAC-3	31	41.95	0.10	2.85	7.38
FRAC-4	31	157.26	0.84	10.49	27.64
FRAC-5	31	782.68	4.63	54.19	138.14
FRAC-6	31	1252.94	6.48	83.99	221.38
FRAC-7	31	2684.02	3.05	174.63	477.16
FRAC-8	31	847.04	4.55	65.84	151.86
TOTWT	31	5770.68	36.29	392.52	1021.09

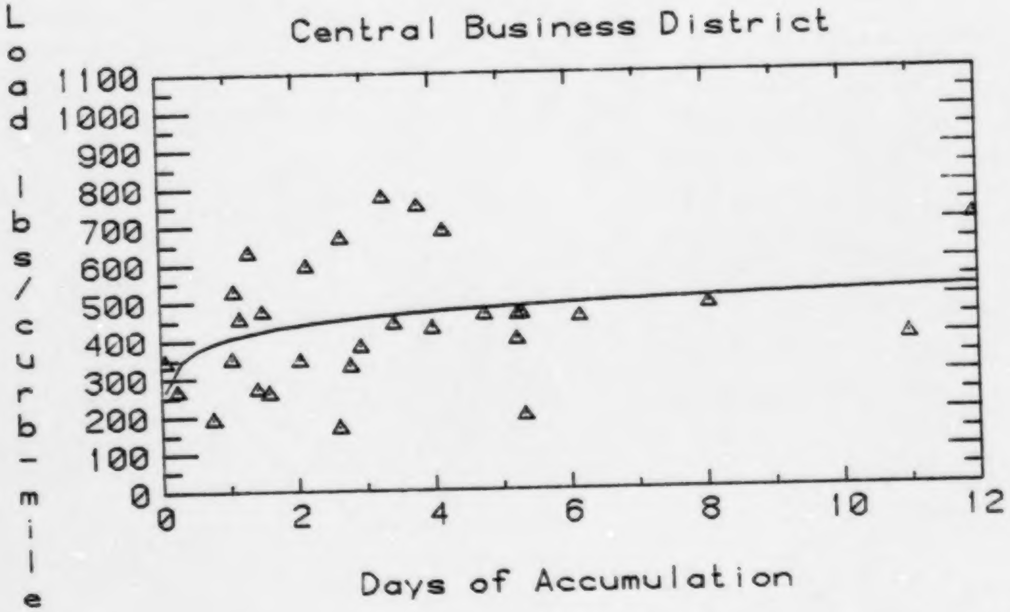
ARDMORE RESIDENTIAL AREA

Variable	N	Maximum Value	Mimimum Value	Mean	Standard Deviation
FRAC-1	31	0.00	0.00	0.00	0.00
FRAC-2	31	1.27	0.01	0.30	0.31
FRAC-3	31	42.52	0.11	2.66	7.46
FRAC-4	31	12.35	0.58	4.56	3.49
FRAC-5	31	97.80	1.73	28.06	23.70
FRAC-6	31	140.52	2.42	51.02	42.42
FRAC-7	31	690.73	4.95	171.23	163.96
FRAC-8	31	340.08	2.03	96.41	102.14
TOTWT	31	1146.14	11.84	280.64	261.34

Street Solids Accumulation Rate Curves

Figure 16





The results suggest that sweeping about every two or three days would be the most effective because at this point, the accumulation curve has leveled off and the frequency of rainfall (from 1948 to 1975) averages every three to four days. Sweeping should occur ideally before every rain fall to get the maximum removal for the minimum cost.

The average percentages that each particle size contributed to the total sample weight is shown in Figure 17. Fraction 9 (>3600 microns) was not included in the total weight calculation because it was considered to be litter and collected by hand in the sampling procedure. The data showed that over 80% of the total sample weight was made up of particles greater than 106 microns. The 212 to 1000 micron size fraction accounted for over 44% of the total sample weight in each study watershed.

Cross Sectional Street Loading:

The 212 to 1000 micron size fraction also accounted for most of the total sample weights recorded during the cross sectional accumulation study. Each of the four sampling sites within a watershed (Figures 11 and 12) were compared. All residential sites were similar while one of the CBD sites (site 1, Third Street) had significantly higher solids associated with the area from the curb out one foot into the street. This was due to construction activities uphill of the study site during sampling periods. For this reason, CBD site one was omitted from the analysis.

An analysis of the cross sectional distribution of street solids showed that the section from the curb out one foot into the street had significantly higher accumulations than any other portion of the street. This was generally consistent for all the particle sizes but was less defined for the size fractions below 45 microns. Figure 18 shows the average cross sectional distribution of street solids for both watersheds. Site number 1 is omitted from the CBD graph because of the construction activities.

It is clear from the cross sectional loading data that street sweeping should concentrate on the section of street within one foot of the curb. In fact, on the average, if the street sweeper only concentrated on the section one foot out from the curb, potentially 80% of the available street solids could be removed.

Average Percent of Each Particle Size

Contributed to Total Weight

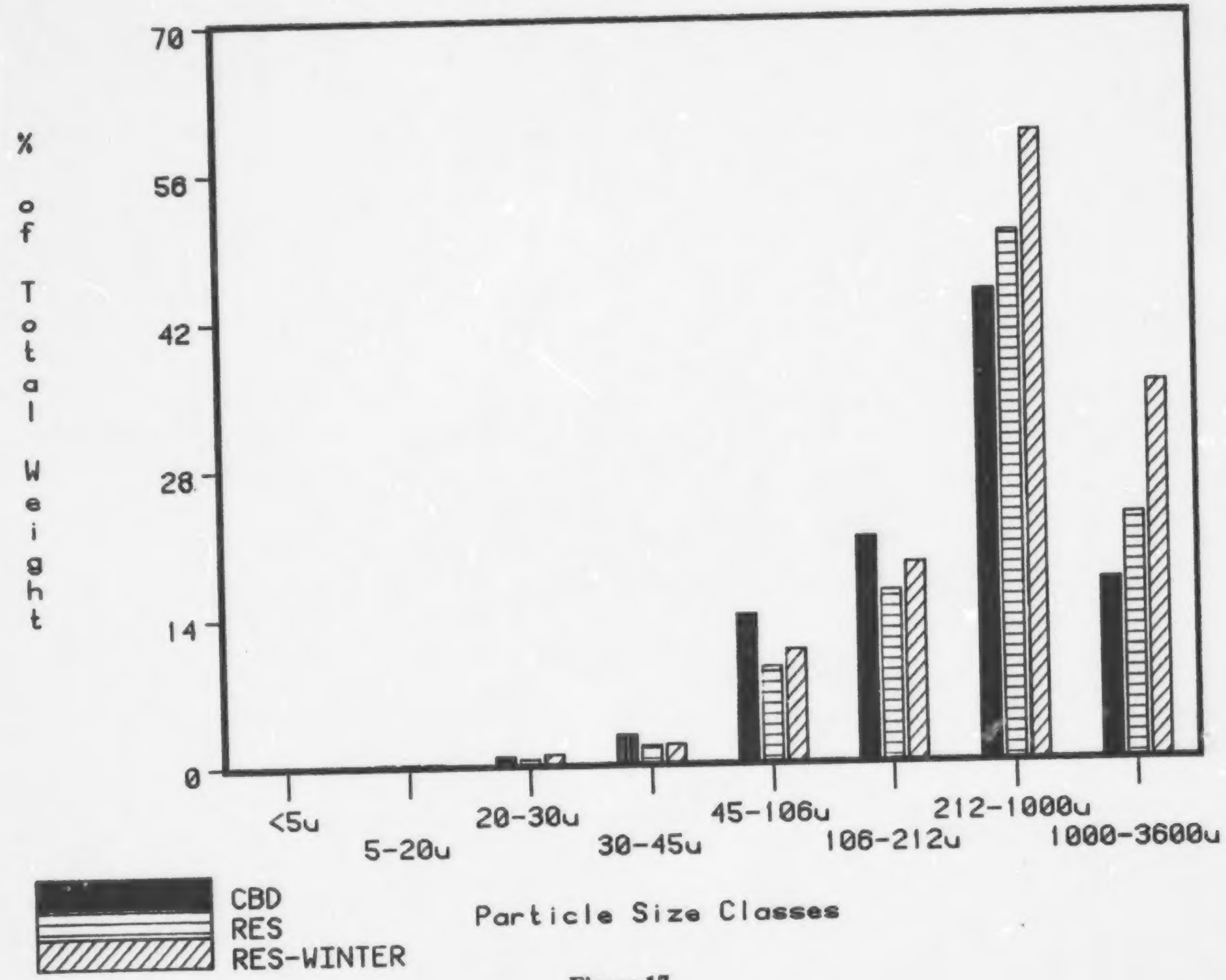
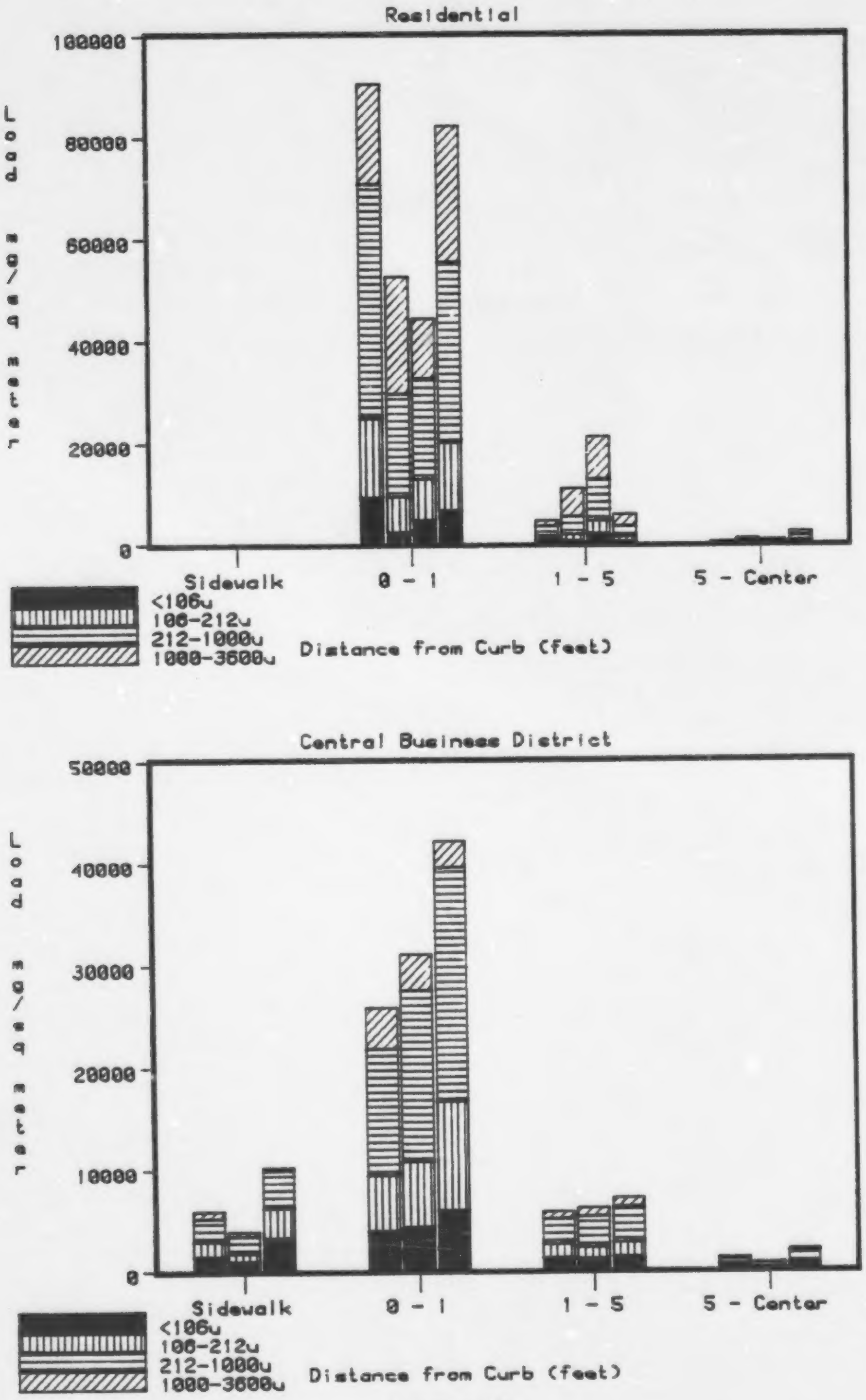


Figure 17

Cross Sectional Distribution



Residential

Central Business District

Figure 18

POLLUTANT PARTICLE SIZE DATA:

In order to completely assess the effects of street sweeping, the type of pollutants removed by the street sweeper must be known. The first step in determining actual pollutant removal by the street sweeper was to find what types of pollutants were associated with street solids.

The data collected showed that the smaller particle size fractions had significantly higher concentrations of pollutants associated with them (Figures 19 thru 22). The less than 5 micron particle size class was omitted from pollutant analysis because sampling did not produce a sufficient amount of solids in this size class. A seasonal analysis showed that in general all seasons have similar pollutant particle size associations. However, in the residential study area, zinc concentrations are significantly higher in the summer and the fall for particle sizes from 45 microns to 1000 microns.

Table 3 and 4 show the mean pollutant concentration of each particle size class. These values will be used in the street sweeping effectiveness section to assess how much pollutant is actually removed by the sweeper. From the information present in these tables, it would seem that a sweeper which concentrated on the smaller size fractions would be more efficient at pollutant removal. When the percent composition of street dirt (Figure 17) is considered, however, it can be seen that the high concentrations associated with the small fractions are cancelled by their low percentage in the total amount of street solids. When the actual amount of pollutant associated with the average kilogram of street dirt is calculated (Table 5), it is apparent that the >45 micron size classes should be controlled.

Mean Pollutant Concentration for Each Particle

Size Class

Residential

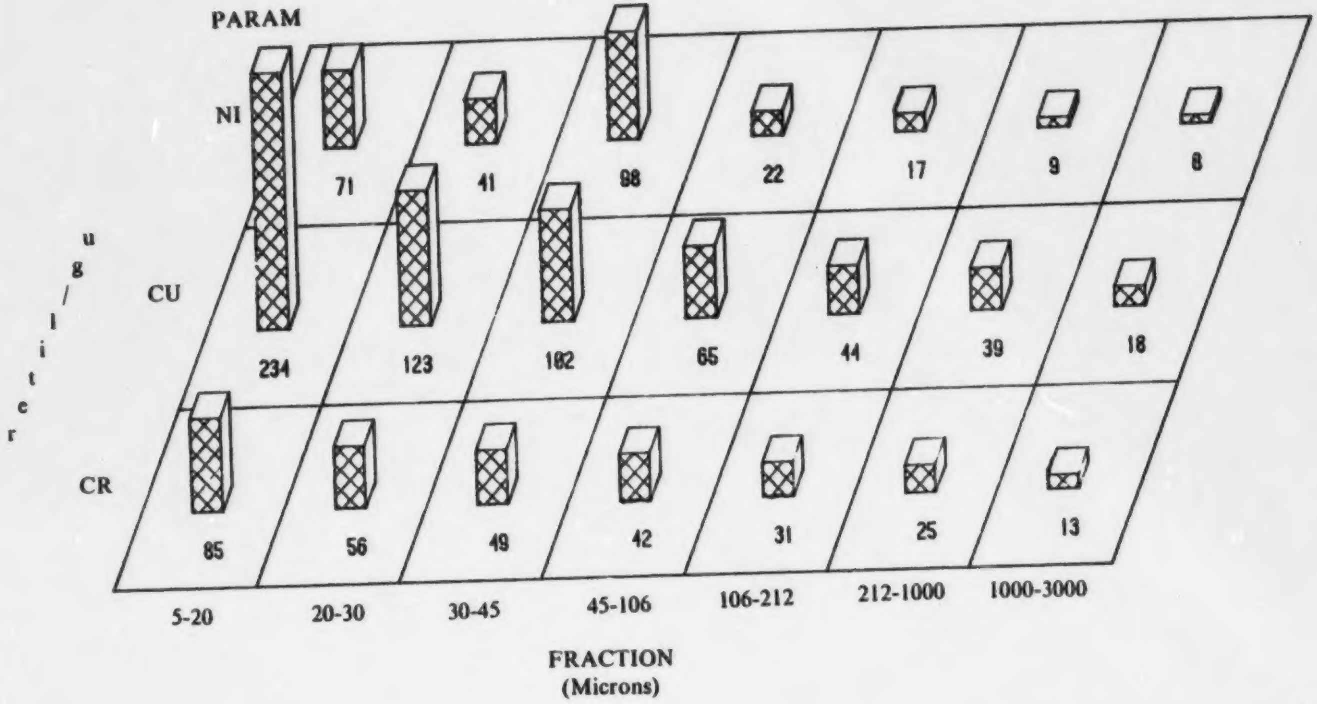


Figure 19

Mean Pollutant Concentration of Each

Particle Size Class

Residential

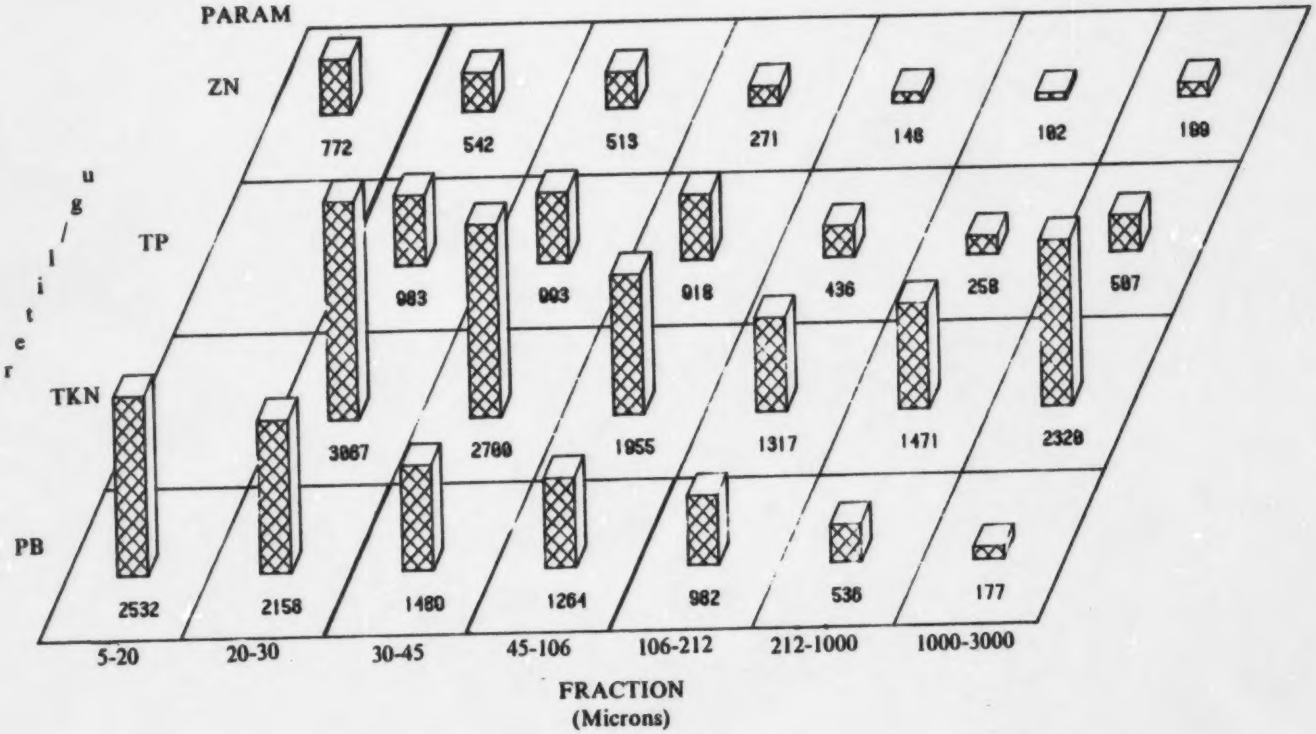


Figure 20

Mean Pollutant Concentration of Each Particle

Size Class

CBD

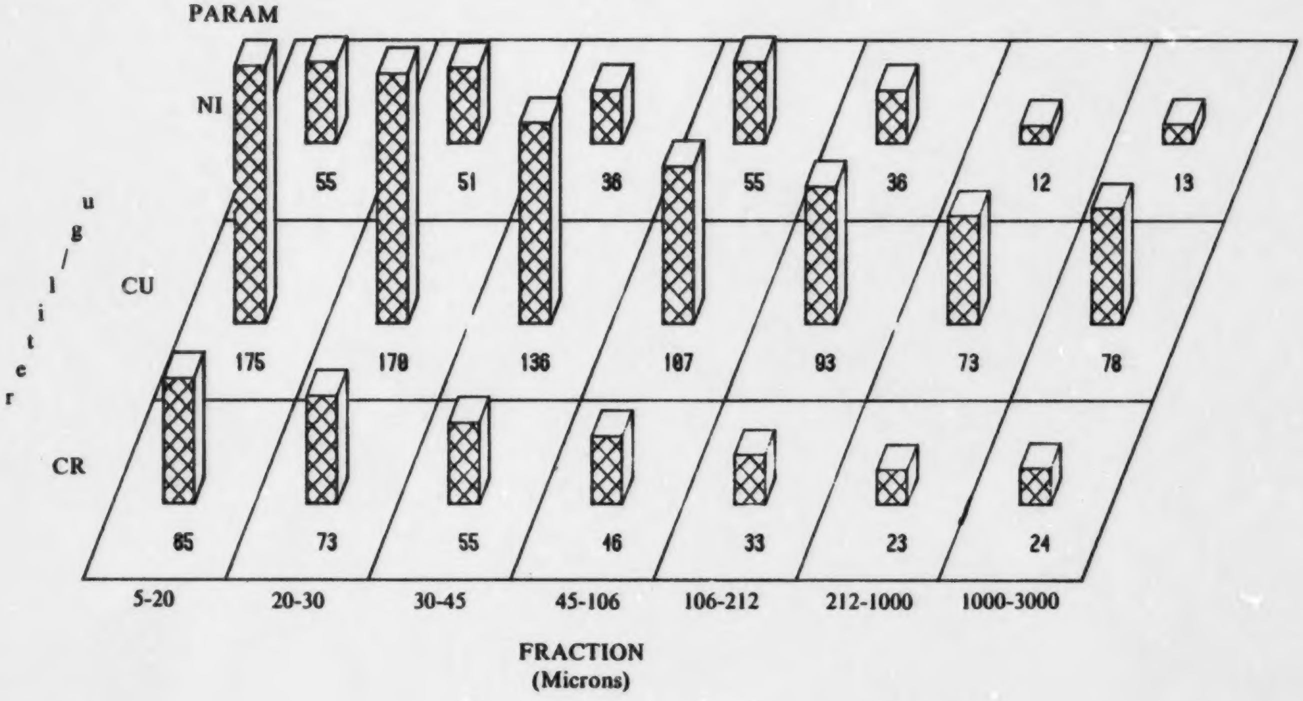


Figure 21

Mean Pollutant Concentrations Associated with Particle Sizes

CBD

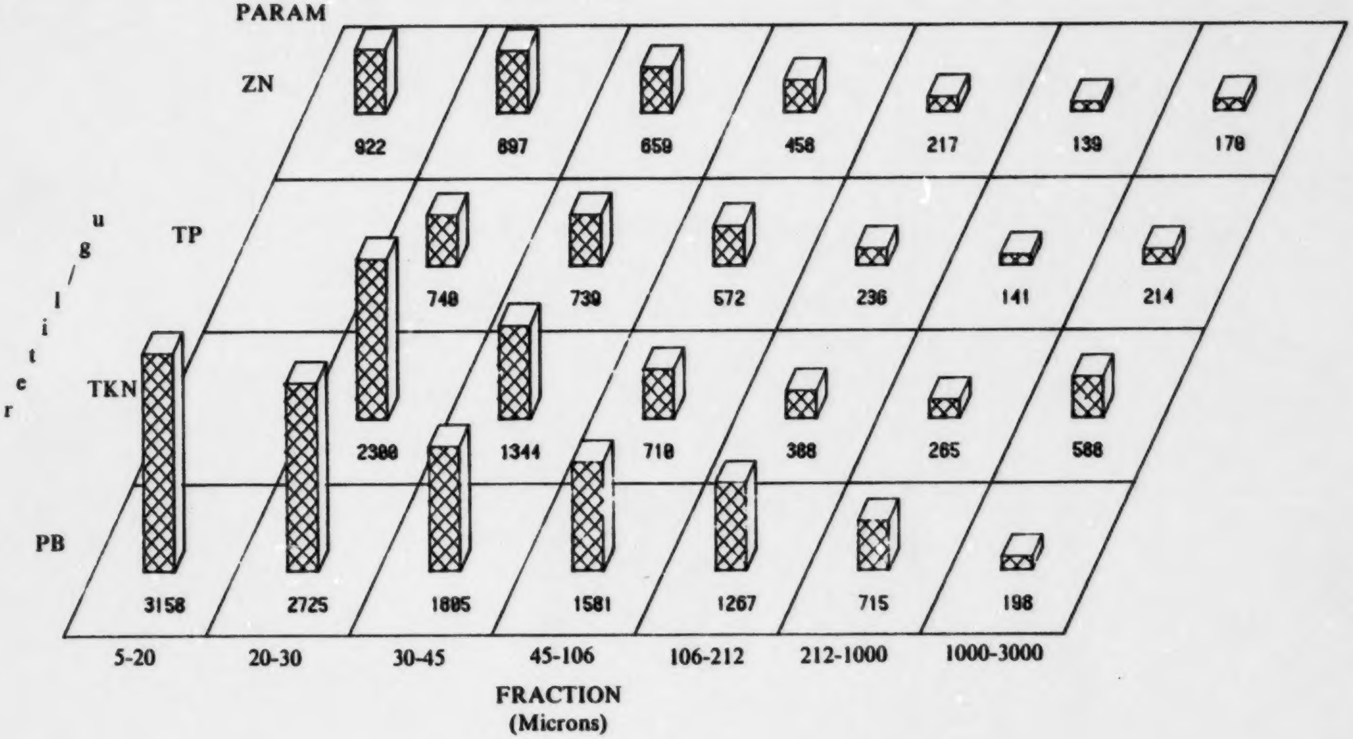


Figure 22

Mean Pollutant Concentration of Each Particle Size Class
(ug/liter)

Central Business District

Parameter	Fraction Sizes (microns)						
	5-20	20-30	30-45	45-106	106-212	212-1000	1000-
TKN	.	2300.00	1343.64	710.00	387.86	265.38	588.25
TP	.	740.00	739.09	571.54	236.43	141.23	213.75
CD	6.17		2.73	1.93	1.01	0.57	2.64
CO	24.50	23.50	21.50	11.85	6.45	3.85	6.00
CR	85.00	73.55	54.69	46.46	32.79	23.04	24.28
CU	175.00	170.00	135.62		93.07	72.82	77.75
HG	1.84	1.50	1.15	0.45	0.08	0.11	0.09
MN	497.40		395.66	327.69	153.44	133.46	283.54
NI	55.30	50.58	35.54	54.69	35.93	12.08	13.25
PB	3158.00	2725.00	1804.62	1580.77	1266.93	714.69	198.35
ZN	922.00	896.67	659.23	458.46	217.29	139.00	170.37
BOD5	.	20000.00	11920.00	4776.92	1957.86	1283.08	5310.42
COD	.	216000.00	302400.00	138692.31	56721.43	26192.31	64225.00

Table 3

Mean Pollutant Concentration of Each Particle Size Class
(ug/liter)
Residential

Parameter	Fraction Sizes (microns)			
	5-20	20-30	30-45	45-106
TKN	.	3066.67	2700.00	1955.00
TP	.	983.33	993.33	918.00
CD	7.05	2.82	2.90	2.35
CO	.	.	.	.
CR	84.50	55.80	49.20	41.70
CU	234.33	122.60	102.40	64.70
HG	.	0.19	0.24	0.11
MN	700.67	337.80	321.13	334.60
NI	71.33	40.60	97.60	21.50
PB	2531.67	2158.00	1480.40	1264.30
ZN	771.67	542.00	512.90	271.10
BOD5	.	11500.00	8874.00	6111.11
COD	.	350000.00	334,750.00	195444.44

	106-212	212-1000	1000-3600
TKN	1317.00	1470.50	2320.00
TP	436.00	257.50	506.80
CD	1.36	1.60	1.08
CO	.	.	.
CR	31.10	24.96	13.09
CU	43.58	38.81	17.89
HG	0.06	0.04	0.06
MN	188.20	135.08	185.80
NI	16.67	8.99	7.85
PB	982.40	535.70	176.50
ZN	147.80	101.54	199.05
BOD5	3370.00	6170.00	13731.00
COD	84000.00	104150.00	281500.00

Table 4

Milligrams of Pollutants in the Average Kilogram of Street Dirt by Particle Size

Central Business District

	5-20	20-30	30-45	45-106	106-212	212-1000	1000-
TKN	-	16	34.93	99.4	81.45	116.77	99.41
TP	-	5.18	19.22	80.02	49.65	62.14	36.12
CD	.02	.03	.07	.27	.21	.25	.45
CO	.05	.16	.56	1.66	1.35	1.69	1.01
CR	.16	.51	1.42	6.50	6.89	10.14	4.10
CU	.33	1.19	3.53	15.22	19.54	32.04	13.14
HG	.00	.01	.03	.06	.02	.05	0.02
MN	.94	3.29	10.29	45.88	32.22	58.72	47.92
NI	.01	.35	0.92	7.66	7.55	5.32	2.24
PB	5.97	19.42	46.9	221.31	266.06	314.46	53.52
ZN	1.74	6.28	17.14	64.18	45.63	61.16	28.79
BOD	-	140.	309.92	668.77	411.15	584.56	899.46
COD	-	1512.	7862.4	19416.92	11911.50	11524.62	10854.03
Residential Study Area							
TKN	-	15.33	45.36	175.95	210.72	720.55	528.96
TP	–	4.92	16.69	82.62	69.76	126.18	115.55
CD	.01	.014	.05	.21	.22	.78	.25
CO	-	-	-	-	-	-	-
CR	.13	2.79	.83	3.75	4.98	12.23	2.99
CU	.35	.613	1.72	5.82	6.97	19.02	4.08
HG	-	.0009	.004	.01	.0096	.02	.01
MN	1.49	1.69	5.40	30.11	30.11	66.18	42.36
NI	.01	.20	1.64	1.94	2.66	4.41	1.790
PB	3.75	10.29	24.86	113.79	157.18	262.5	40.24
ZN	1.14	2.71	8.62	24.4	23.65	49.76	45.38
BOD	-	57.5	149	550	539.2	3023.	3131
COD	-	17.50	5624	17590	13440	51034	64182

Table 5

STREET SWEEPING PRACTICE PERFORMANCE:

The performance of the street sweeping program has been considered in two separate ways. First, the removal efficiency of actually sweeping the watershed is considered as sweeping efficiency. Second, the efficiency of carrying out sweeping on available sweeping days is considered as practice efficiency. Both sweeping and practice efficiency were studied under real world conditions with no attempt made to estimate the removal efficiency of the specific type of street sweeper used in the Winston-Salem area. However, the data collected can be used to show the removal that can be expected under a typical street sweeping program.

Sweeping Efficiency:

Table 6 shows the average removal efficiencies for each of the particle size fractions in the two study watersheds. While no statistical seasonal differences were seen in either watershed, the winter season in the residential watershed did have consistently lower removal for most size fractions. This can again be attributed to leaf fall. In the residential watershed the sweeper has a lower removal efficiency than it does in the CBD. This is because the CBD has less debris from residential activities and because sweeping in the CBD is conducted when parking in the area is negligible (2200 to 2400 hours).

From the sweeper efficiency data it is apparent that the sweeper is more efficient at removing larger size fractions. When the relationship between percent removal and particle size is plotted (Figure 23) it can be seen that in both the CBD and residential watersheds the percent removal levels off at about 45 microns. Above this point removals average about 42% in the CBD and 26% in the residential watershed. The relatively low significance of the size fractions less than 45 microns can be seen again in percent removal for all of the size fractions combined. The total weight removal in the CBD is 42% (the average of the size fraction greater than >45 microns) and the total weight removal for the residential watershed is 29% (only slightly more than the >45 microns average). The particle size distribution before and after sweeping is shown in Figure 24.

A regression was run to examine the relationship between total solids percent removal and the initial street load. The analysis did not show any significant relationship.

The sweeper efficiency results in conjunction with the accumulation rate results and the pollutant/particle size results show clearly that the ideal sweeping program should be geared to the particle sizes over 45 microns. In general, the sweeping program does have its best removal efficiency in the >45 micron area. The average amounts of pollutants actually removed during an average sweeping period are presented in Table 7.

Practice Efficiency:

The percentage of "available sweeping days" that the watershed was swept each month during the study was calculated. An "available day" is defined as any non-raining workday, meaning that at 100% efficiency the watershed would be swept five times per week except for holidays and rain days. The results showed that the CBD watershed was swept about 90% of the available sweeping days with the winter season only averaging 75% because of snowfall. The residential watershed however only averaged 60% with spring and summer averaging 85% while fall and winter averaged less than 25% because of leaf fall and snowfall. Because removal efficiency does not vary with initial street load and because the street solids accumulation levels off so quickly, (often in one day) the most important time to sweep would be just prior to a rain event. As a final measure of practice efficiency, the percent of time the streets were swept prior to a rain event was calculated for both study watersheds. The number of days immediately prior to a rain event averaged four per month during the study. Over all the seasons, the CBD was swept 68% of the days prior to rain events, while the residential area was swept only 40% of those days. Of the 40% in the residential area, only 16% of the days prior to a rain event were swept in the autumn, again owing to leaf fall.

From the practice efficiency study it can be seen that even though the sweeper is able to remove an average of 42% of the street solids for the CBD and 29% for the residential areas during its normal sweeping of the watersheds, the actual removal of solids by the program is considerably less because the sweeper is not always sweeping the watersheds during the critical periods.

Table 6

REMFRAC* IS PERCENT REMOVAL FOR FRACTION * FRACTIONS 1, 2, 3, 4, 5, 6, 7, AND 8 ARE <5, 5-20, 20-30, 30-45, 45-106, 106-212, AND 212-1000 MICRONS RESPECTIVELY

VARIABLE	N	MAXIMUM VALUE	MINIMUM VALUE	MEAN	STANDARD DEVIATION
STATION = CBD					
REMFRAC2	15	100.00	-175.00	42.13	72.70
REMFRAC3	18	82.00	-144.00	16.61	52.05
REMFRAC4	19	67.00	-26.00	21.89	25.71
REMFRAC5	18	62.00	-13.00	33.94	19.64
REMFRAC6	18	71.00	-4.00	41.00	19.08
REMFRAC7	18	78.00	17.00	45.94	16.69
REMFRAC8	18	86.00	-4.00	45.98	29.97
REMTOT	18	74.00	14.00	42.89	17.26
REMLIT	18	100.00	-439.00	31.50	128.59
STATION = RES					
REMFRAC2	19	100.00	-800.00	-70.79	253.42
REMFRAC3	18	100.00	-427.00	-8.78	127.12
REMFRAC4	21	79.00	-164.00	-3.86	61.92
REMFRAC5	21	82.00	-58.00	19.00	38.50
REMFRAC6	21	89.00	-74.00	33.48	36.27
REMFRAC7	21	96.00	-249.00	27.81	69.48
REMFRAC8	21	97.00	-187.00	25.05	62.27
REMTOT	21	95.00	-174.00	29.00	54.93
REMLIT	21	100.00	-123.00	31.57	67.35

Percent Removal by Particle Size

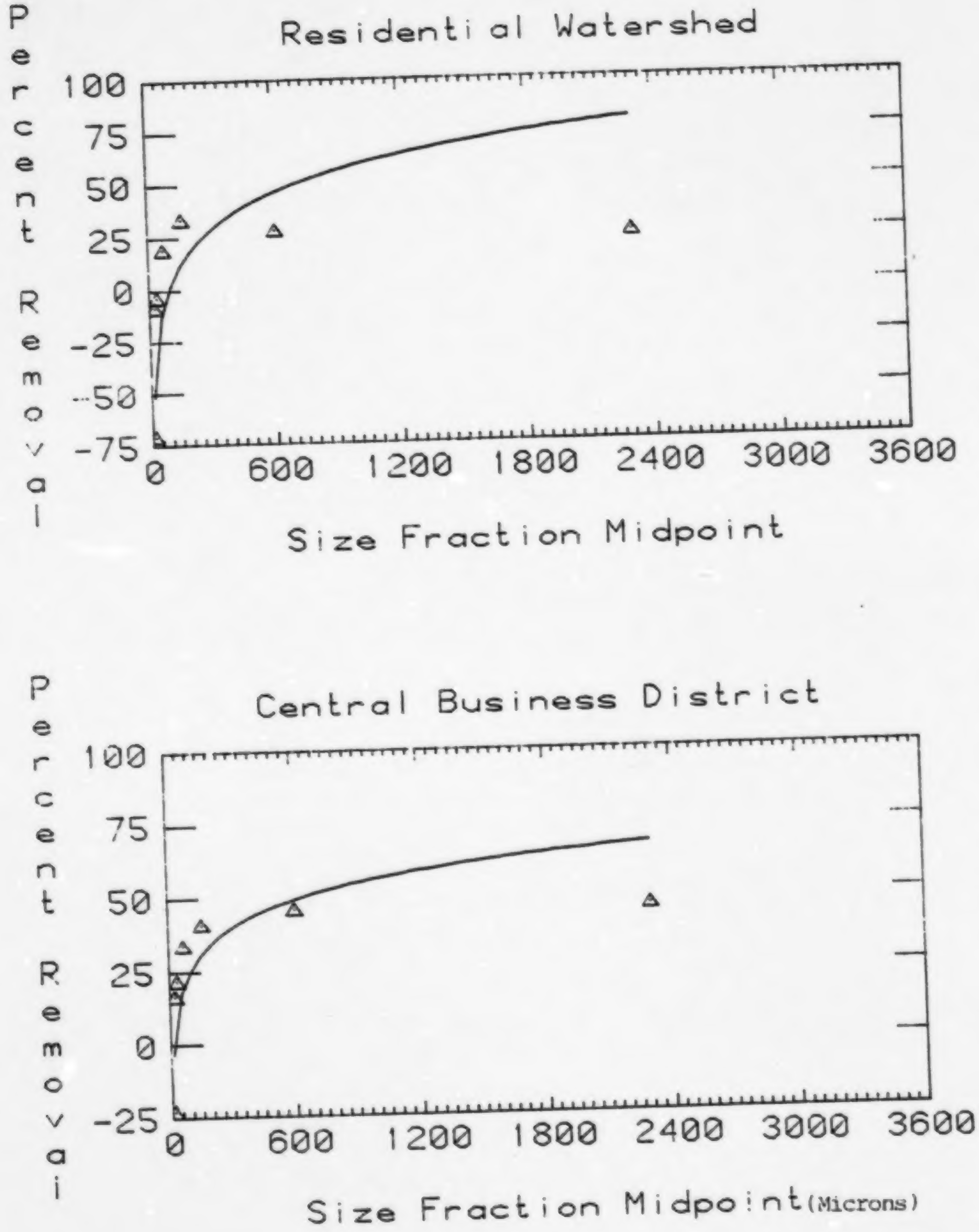


Figure 23

Particle Size Distribution Before and After Sweeping

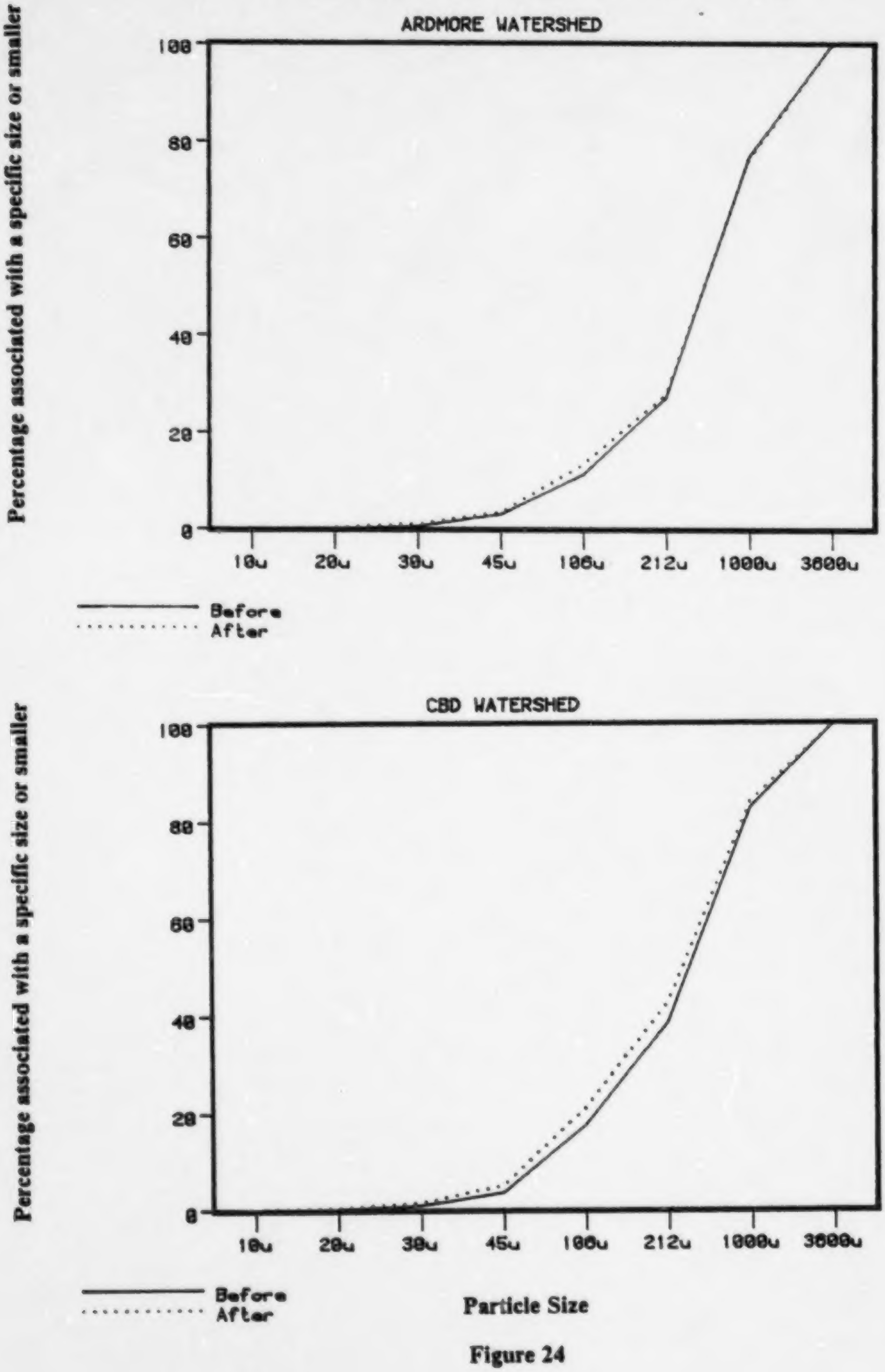


Figure 24

Table 7

Average Amounts of Pollutants Removed (lbs.)

CBD

	5-20	20-30	30-45	45-106	106-212	212-1000	1000-3600
TKN	-	.76	8.02	182.82	280.48	936.79	300.95
TP	-	.25	4.41	147.17	170.97	498.52	109.35
CD	.00042	.00142	.016	.5	.72	2.01	1.36
CO	.001	.0076	.13	3.05	4.65	13.56	3.06
CR	.003	.024	.33	11.95	23.73	81.35	12.41
CU	.007	.056	.81	27.99	67.29	257.04	39.78
HG	0	.0005	.01	.11	.07	.4	.06
MN	.02	.16	2.36	84.38	110.95	471.08	145.07
NI	.00021	.02	.21	14.09	26	42.68	6.78
PB	.13	.92	10.77	407.04	916.2	2522.76	162.02
ZN	.04	.3	3.94	118.04	157.13	490.66	87.16
BOD	-	6.63	71.17	1230	1415.83	4689.63	2722.95
COD	-	71.58	1805.44	35711.79	41018.3	92456.26	32858.6

RES

	5-20	20-30	30-45	45-106	106-212	212-1000	1000-3600
TKN	-	-	-	93.81	359.94	3431.49	1277.48
TP	-	-	-	44.05	119.16	600.86	279.06
CD	-	-	-	.11	.38	3.71	.6
CO	-	-	-	-	-	-	-
CR	-	-	-	2.0	8.51	58.24	7.22
CU	-	-	-	3.1	11.91	90.57	9.85
HG	-	-	-	.01	.02	.1	.02
MN	-	-	-	16.05	51.43	315.14	102.3
NI	-	-	-	1.03	4.54	21.0	4.32
PB	-	-	-	60.65	268.49	1250.0	97.18
ZN	-	-	-	13.01	40.4	236.95	109.6
BOD	-	-	-	293.23	921.03	14395.25	7561.58
COD	-	-	-	9377.9	22957.5	243019.2	155004.

WATER QUALITY EFFECTS:

The most important relationship which could exist would be one in which a street sweeping program showed a direct improvement in the event mean storm concentration. To investigate this relationship water quality samples were collected on every possible storm event occurring during the study period. Recorded along with the appropriate water quality and rainfall information was the amount of time prior to the storm that the streets were cleaned by either street sweeping or previous rainfall. The study design of one season of sweeping alternating with a season of no sweeping yields data which gave good sweeping coverage from swept within one day to swept over eight days.

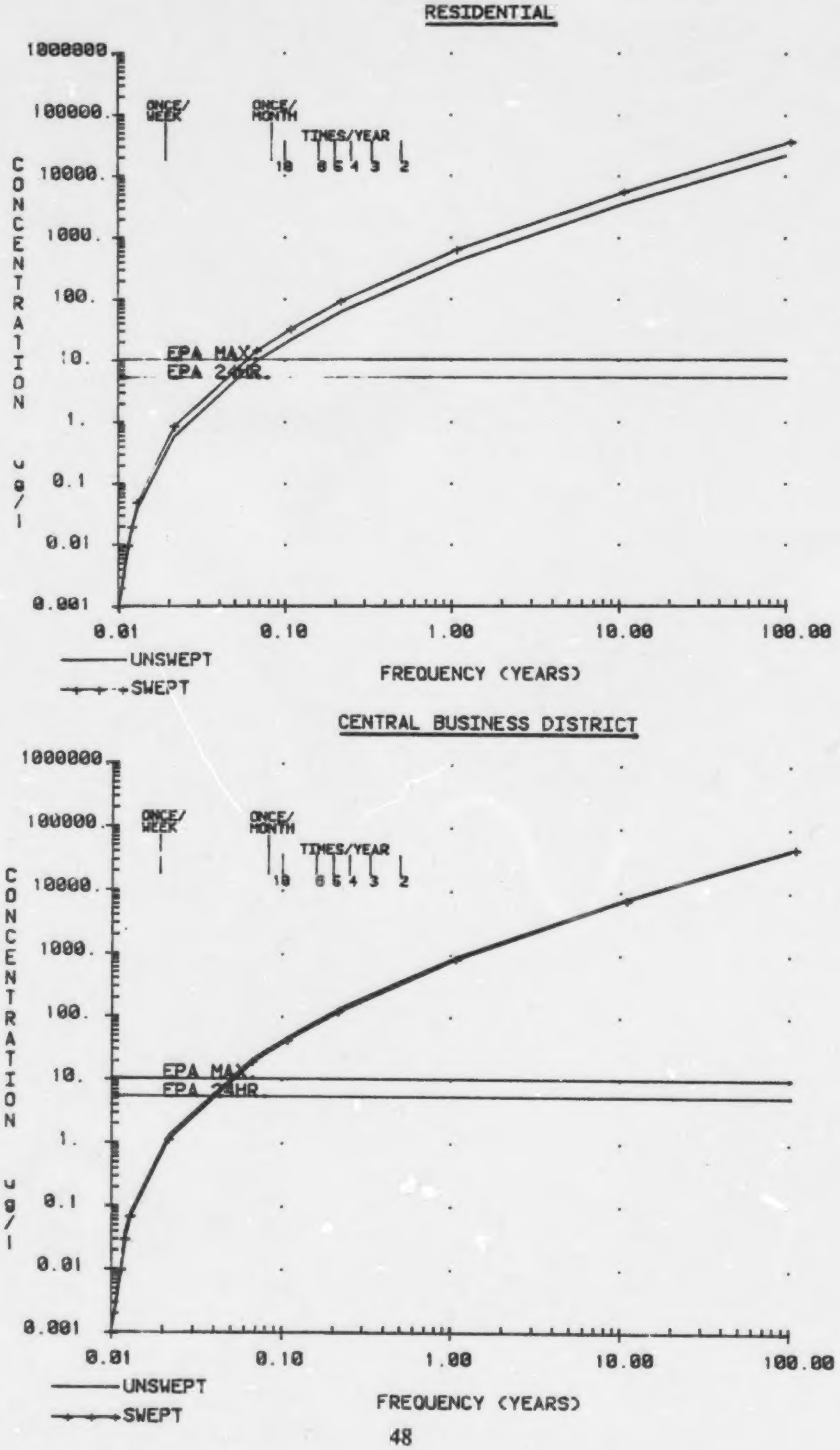
The sweeping program was developed to provide control (no sweeping) and sweeping water quality information for each season. As designed, sweeping was done five times per week during the sweeping season and not at all during the control season which was the same season one year later. The major assumption of this method was that the two seasons to be compared would have generally the same type of storms occurring during both control and sweeping periods. The major benefit of the approach was that there were no physical differences in the control and sweeping watersheds.

Comparisons of sweeping and not having been swept were done on the log-normal transformation of the event mean concentrations. The first analysis compared storms which were swept within twenty-four hours prior to the event with those which had more than one day of accumulation using a student's t-test. The results of this first test showed no significant street sweeping benefit for any parameter in either watershed. In fact, the data showed that in the residential watershed street sweeping may actually have a significantly detrimental effect on ammonia, nitrite/nitrate and copper. This was possibly due to the street sweeper breaking up large particles and making them more available for washoff, or, the effect of armorizing which is the shielding of the smaller particles by the larger particles. The larger particles are removed by the sweeper thus making the smaller particles more susceptible for washoff.

Similar comparisons were completed comparing events swept within two days to those having over two days of accumulation, events swept within three days to those having over three days of accumulation and so on through events swept within eight days to those having over eight days of accumulation. The purpose of these comparisons was to find a sweeping frequency which might show a water quality benefit. Again, no street sweeping benefit was shown in these analyses. The water quality data was next divided into nine subsets. Subset one was events which occurred within one day of sweeping, subset two was events which occurred after having between one and two days of accumulation, etc., such that subset nine was events which occurred after eight or more days of no sweeping. These subsets were then compared using a Ducans Multiple Range test. The results showed that the subsets were not statistically different from each other.

Using the basic approach presented in Appendix C of the preliminary results report of the NURP program (EPA, 1982) frequency of occurrence curves were developed for sweeping and non-sweeping event mean concentrations (Figures 25-34). Referenced on some of the curves are the EPA toxicity and 24 hour standards. The figures show the effect of runoff on the quality of the urban stream and display again the ineffectiveness of street sweeping at reducing runoff pollution.

The general statistics for swept and not-swept are presented in Tables 8 and 9. However, because for most parameters no sweeping differences were detected, the data was combined to calculate the average storm load in pounds. The average storm load for each parameter is compared to the average rainfall load (times the average runoff coefficient) in Table 10. The summary shows that rainfall can be a major contributor to some pollutant loads. This may be part of the reason why street sweeping shows little effect.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CONCENTRATION ug/l
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WEEK
ONCE/
MONTH
TIMES/YEAR
10
6 5 4 3 2
EPA MAX.
EPA 24HR.
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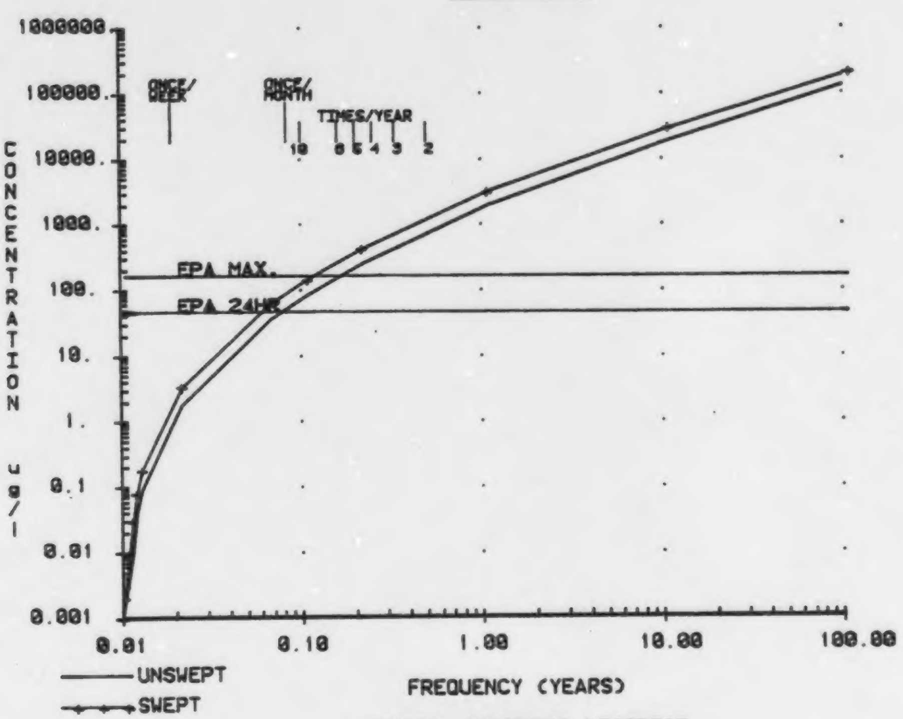
FREQUENCY (YEARS)
UNSWEPT
SWEPT

Figure 25

CU

Figure 26

ZN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TIMES/YEAR
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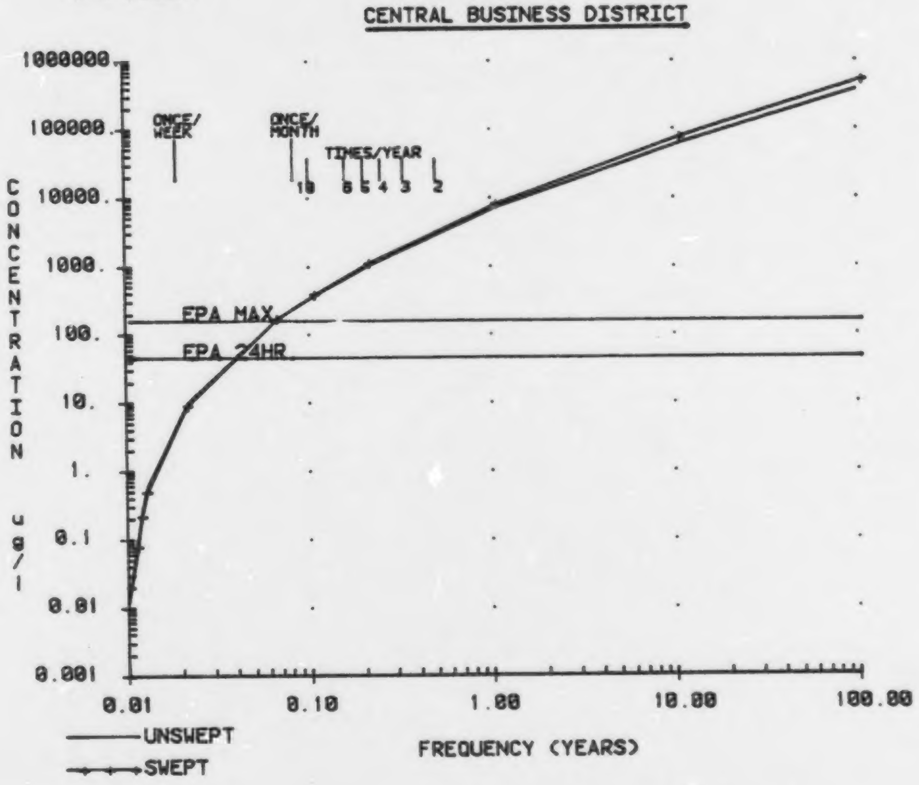
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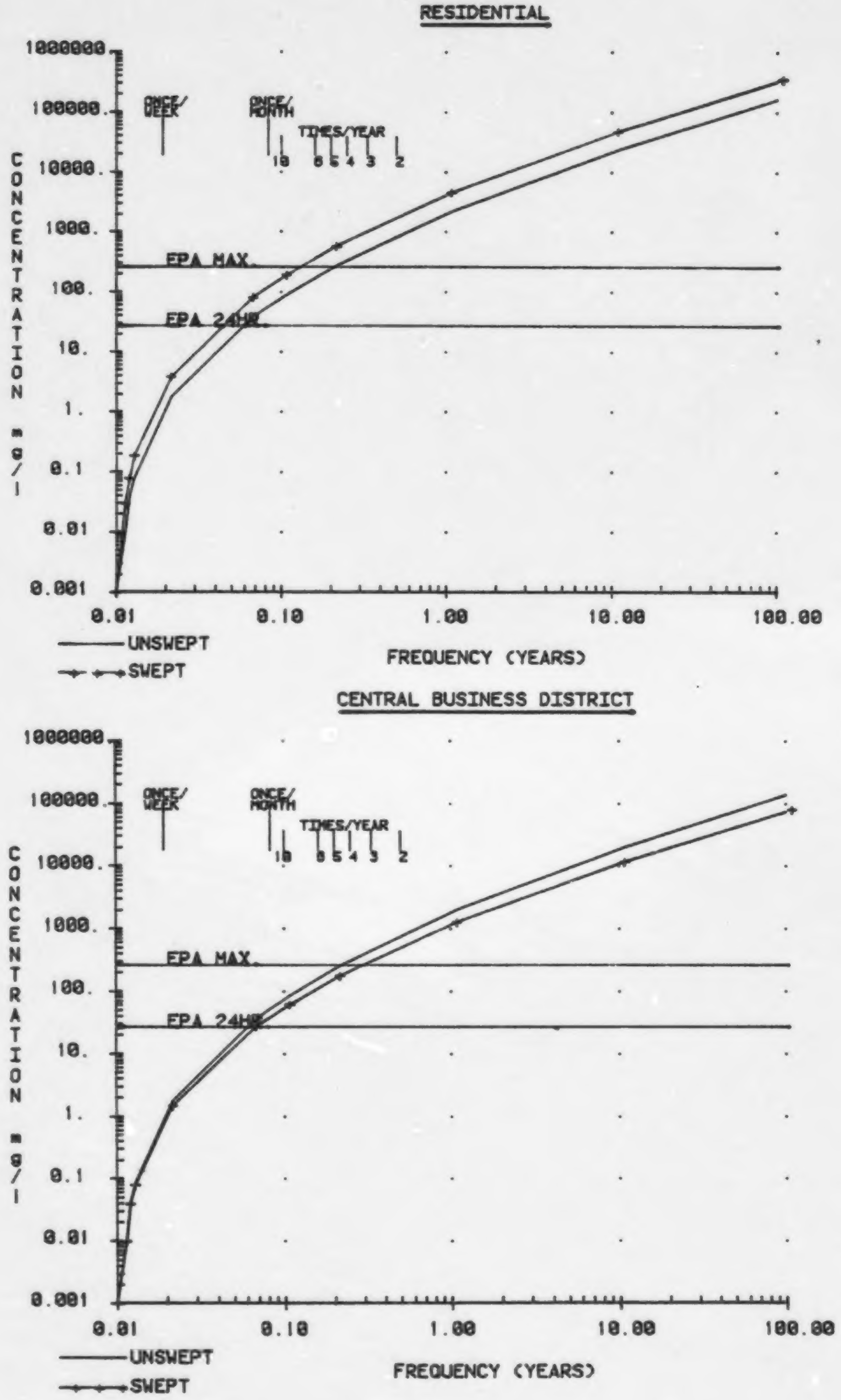
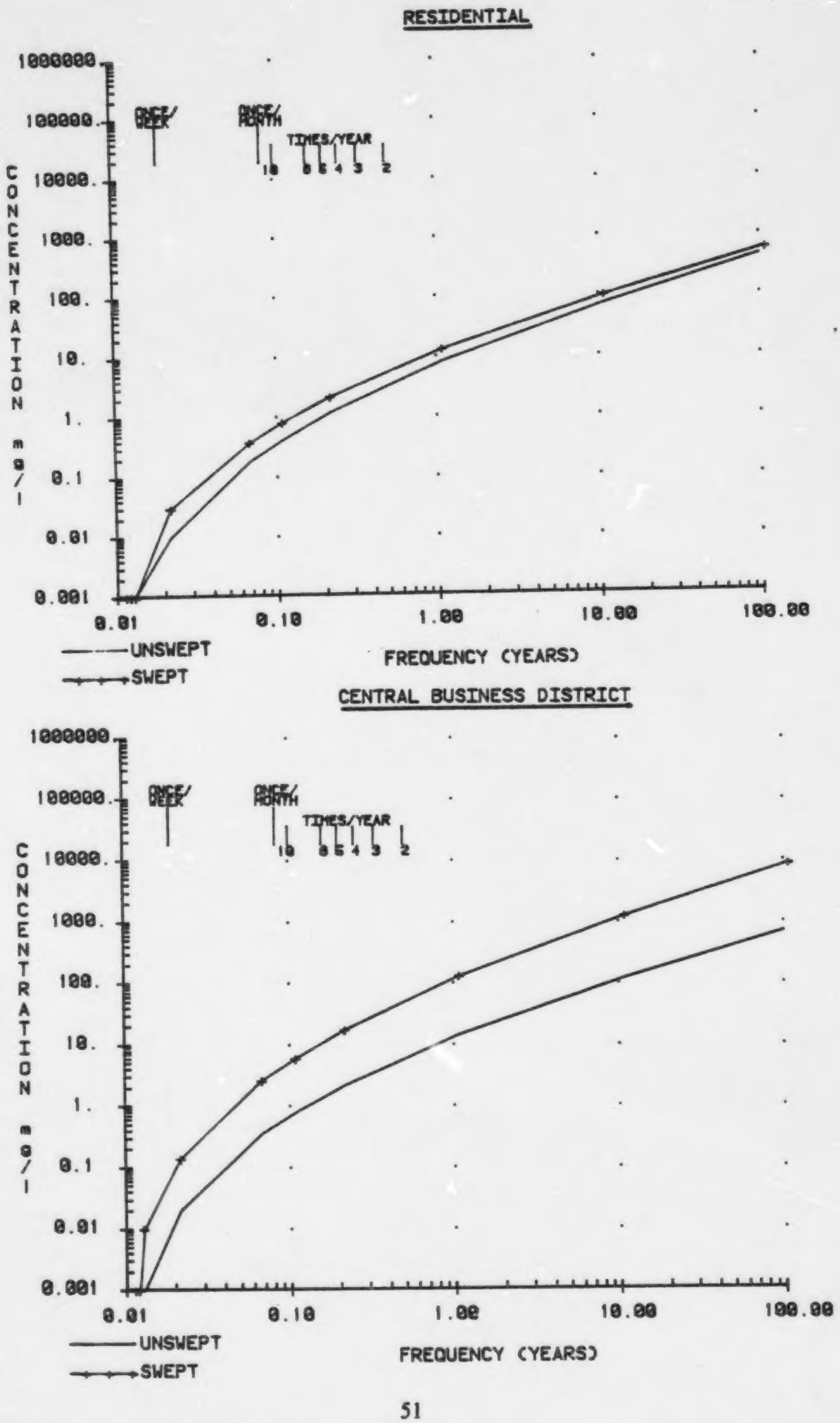


Figure 27

TSS

Figure 28

NO_3



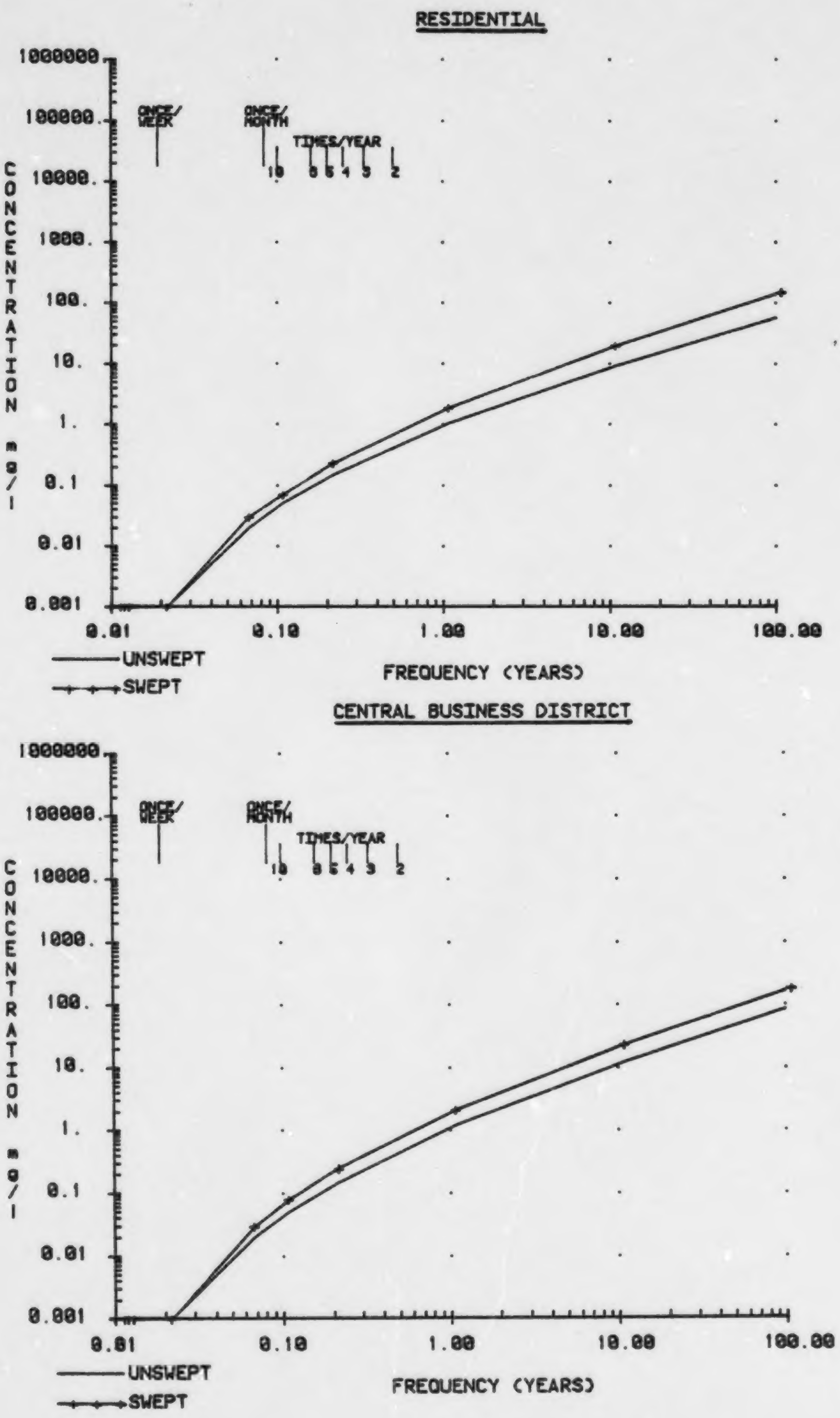


Figure 29

TOP

Figure 30

TP

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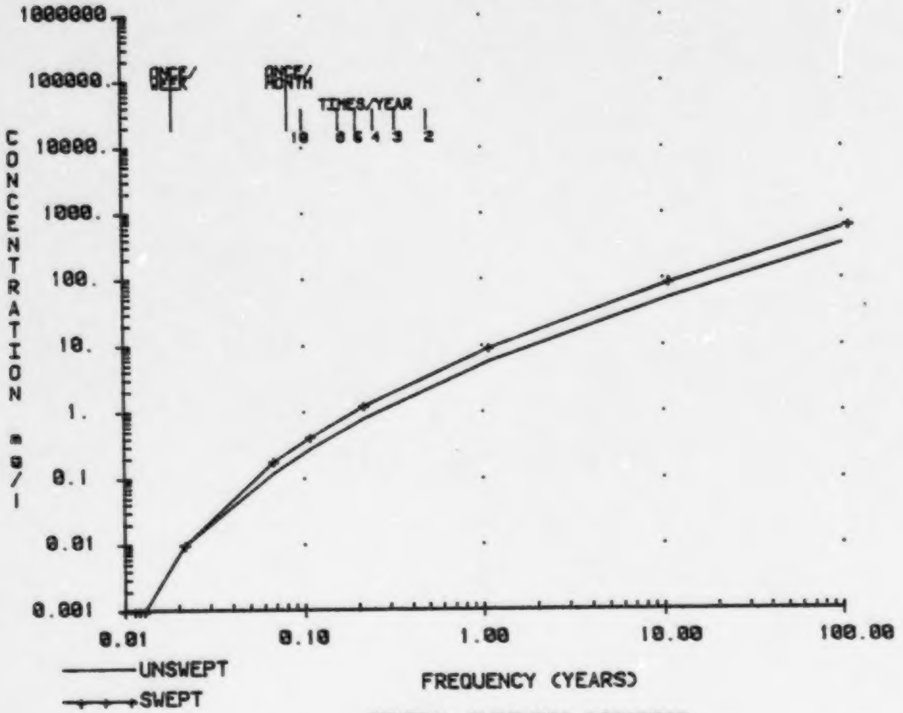
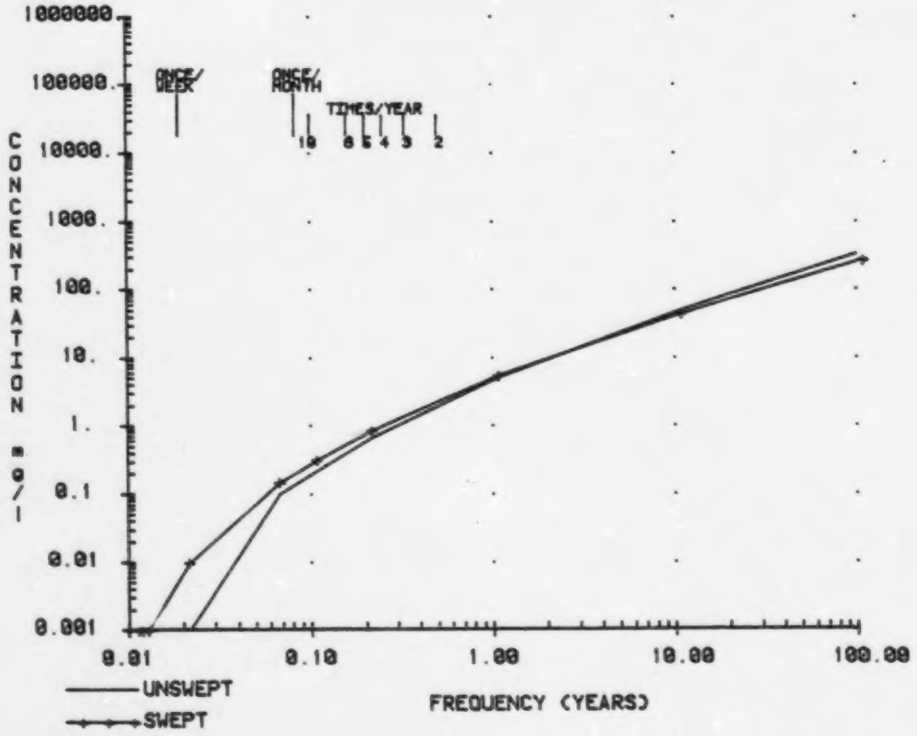
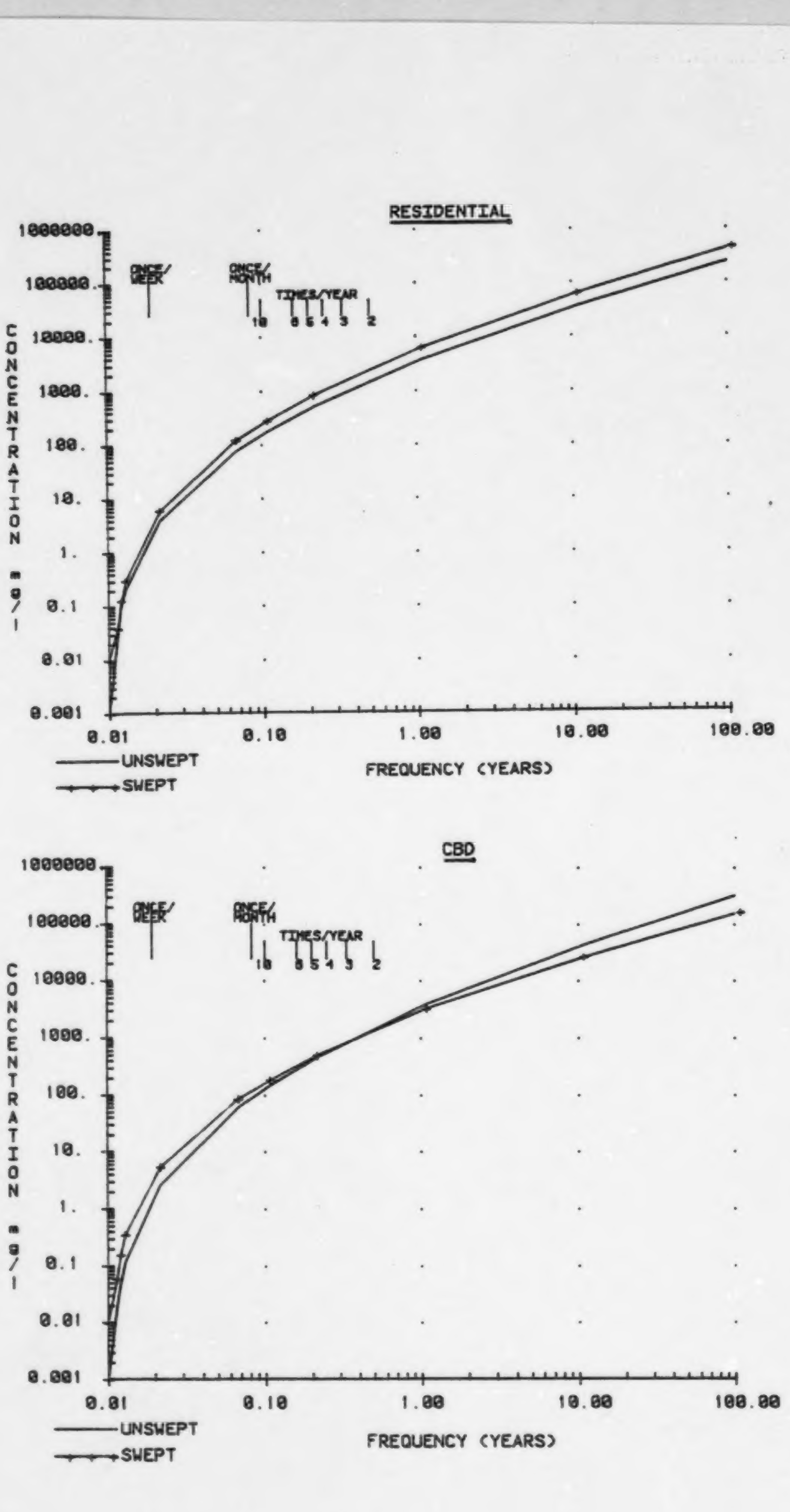


CENTRAL BUSINESS DISTRICT

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CONCENTRATION mg/l
ONCE/ WEEK
ONCE/ MONTH
TIMES/YEAR
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FREQUENCY (YEARS)
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CONCENTRATION mg/l
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FREQUENCY (YEARS)
UNSWEPT
SWEPT

Figure 31

TS

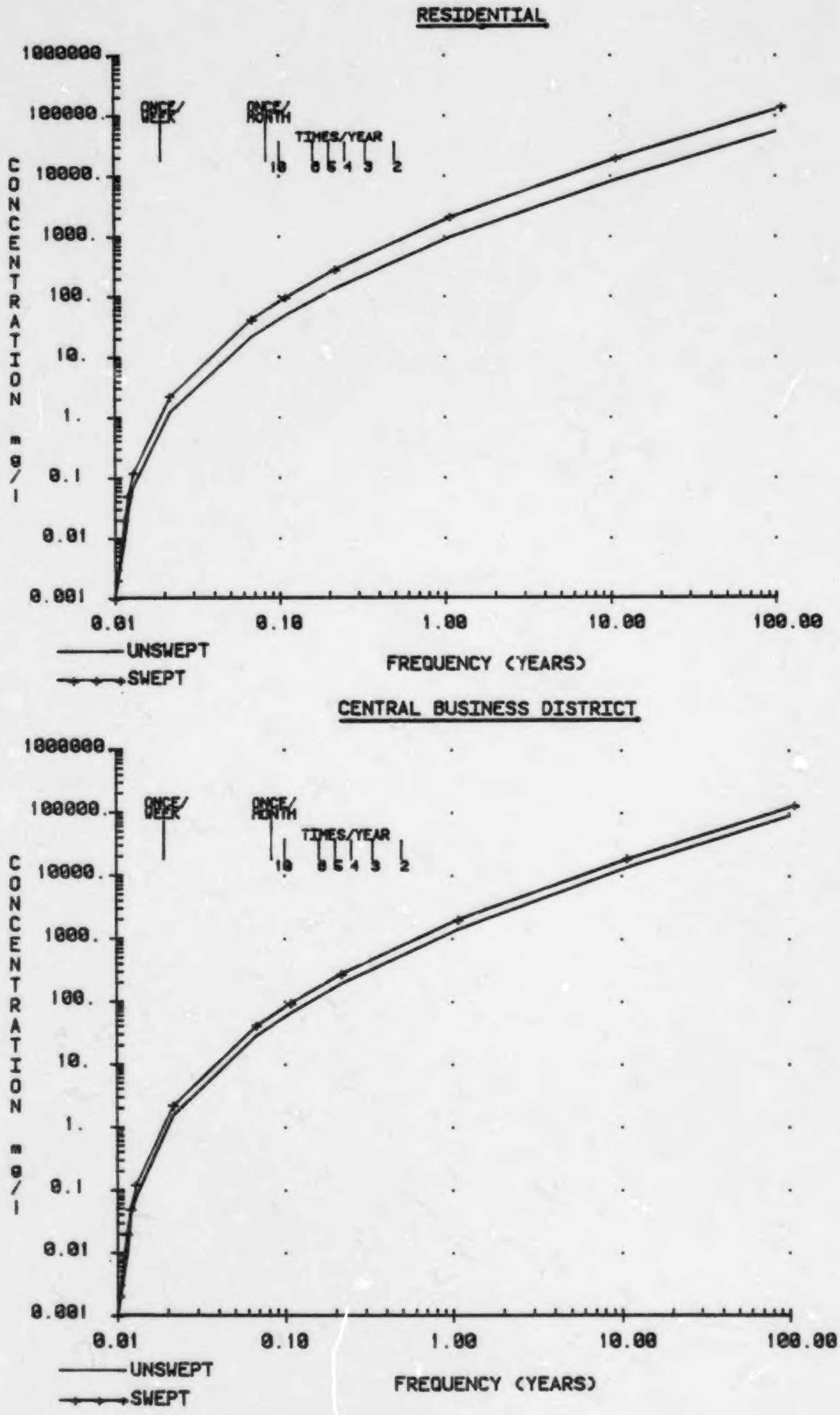
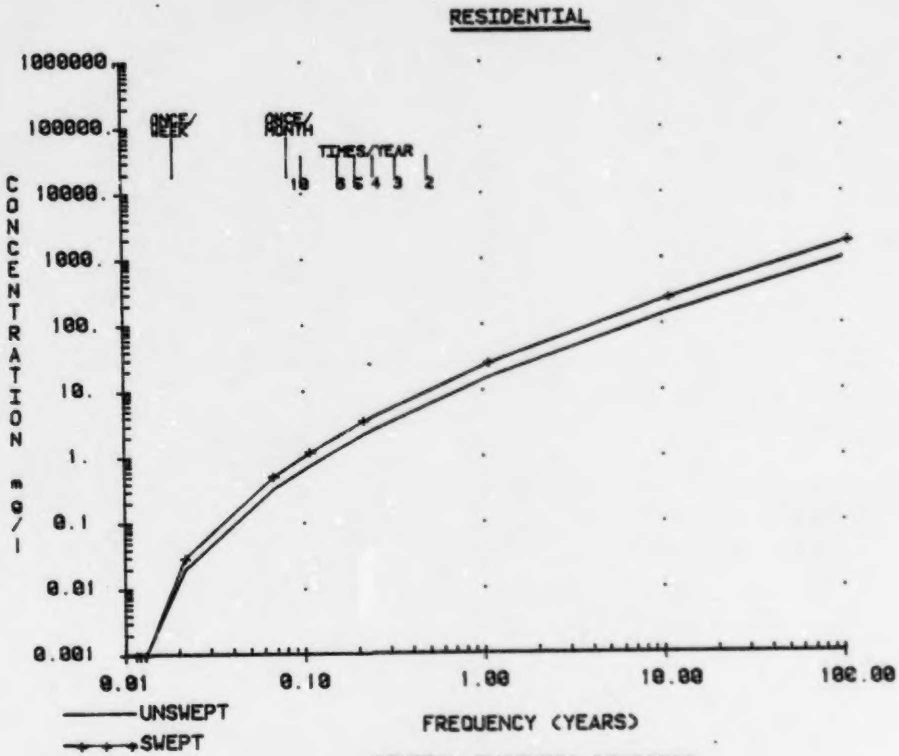


Figure 32

COD

Figure 33

TKN



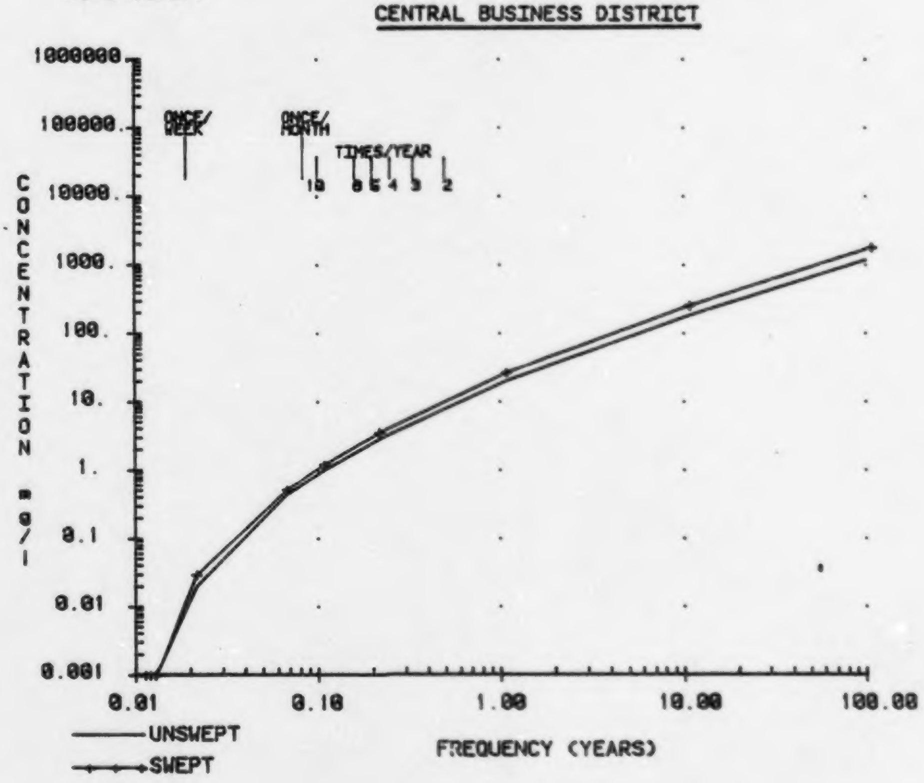


Figure 34

NH$_3$

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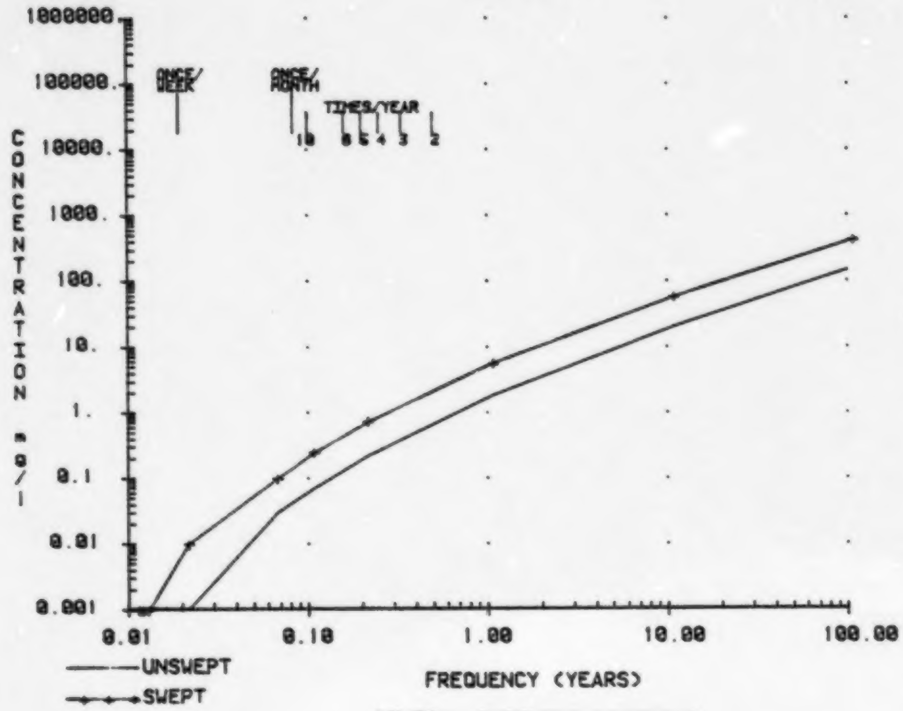
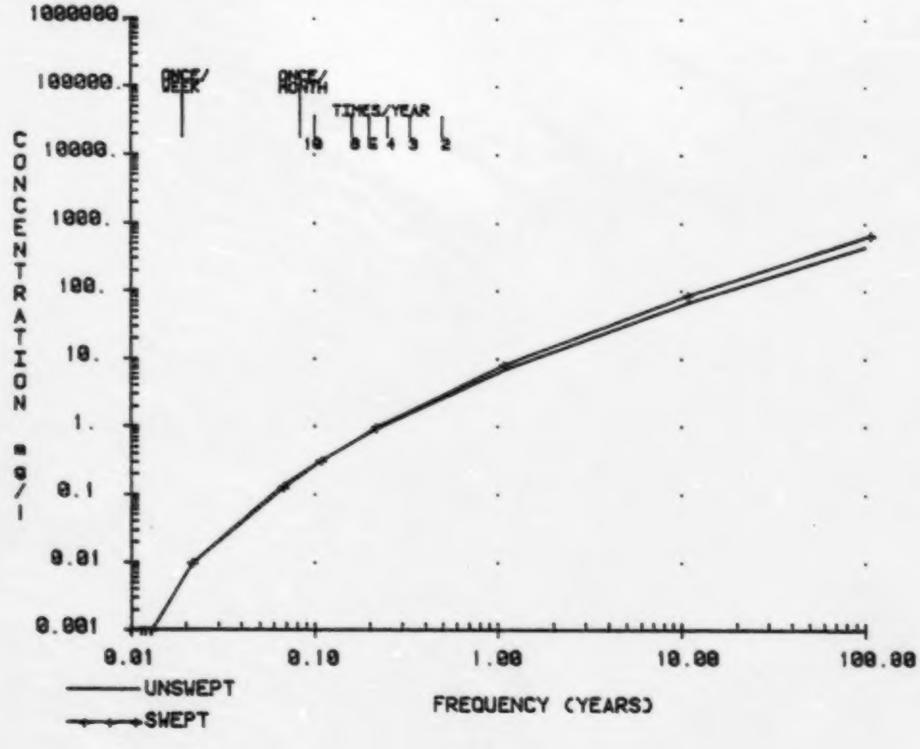


CENTRAL BUSINESS DISTRICT



Central Business District

SWEPT WITHIN 1 DAY

(Concentrations in milligrams/liter)

VARIABLE	N	MEAN	STANDARD DEVIATION	MINIMUM VALUE	MAXIMUM VALUE	STD ERROR OF MEAN
			NOT SWEPT			
TS	28	370.20	505.48	76.70	2743.23	95.53
TSS	29	172.16	165.84	17.69	720.22	30.80
BOD	11	18.45	14.64	4.40	50.95	4.41
COD	20	118.73	91.78	38.70	376.66	20.52
TKN	29	1.56	1.03	0.44	4.74	0.19
NH_3	29	0.58	0.47	0.10	2.20	0.09
NO_3	29	1.06	0.48	0.41	1.99	0.09
TP	29	0.42	0.36	0.12	1.95	0.07
TOP	29	0.10	0.11	0.00	0.61	0.02
CU	29	0.06	0.36	0.28	0.19	0.68
PB	29	0.41	0.34	0.46	0.16	0.64
ZN	29	0.54	0.29	0.17	0.14	0.54
HG	16	0.16	0.64	0.00	0.25	0.16
			SWEPT			
TS	14	244.05	106.57	112.27	527.87	28.48
TSS	13	102.63	69.67	29.36	214.49	19.32
BOD	6	22.00	16.84	4.95	53.60	6.87
COD	9	165.09	122.31	29.40	410.53	40.77
TKN	14	2.20	1.79	0.68	7.89	0.48
NH_3	14	0.74	0.91	0.07	3.74	0.24
NO_3	14	1.37	1.07	0.33	4.57	0.29
TP	14	0.40	0.17	0.19	0.83	0.04
TOP	14	0.19	0.25	0.03	1.01	0.07
CU	14	0.66	0.38	0.25	0.19	0.10
PB	14	0.42	0.40	0.11	0.14	0.10
ZN	13	0.65	0.46	0.29	0.20	0.12
HG	9	0.36	0.41	0.00	1.18	0.14

Table 8

Residential

SWEPT WITHIN 1 DAY
(Concentrations in milligrams/liter)

VARIABLE	N	MEAN	STANDARD DEVIATION	MINIMUM VALUE	MAXIMUM VALUE	STD ERROR OF MEAN
NOT SWEPT						
TS	36	308.74	229.72	90.50	956.42	38.29
TSS	36	197.54	217.01	12.28	905.82	36.17
BOD	3	8.12	2.71	5.47	10.90	1.57
COD	18	77.02	47.33	21.01	184.31	11.16
TKN	36	1.30	0.97	0.22	3.73	0.16
NH_3	36	0.17	0.22	0.02	0.97	0.04
NO_3	36	0.62	0.37	0.03	2.19	0.06
TP	36	0.45	0.30	0.10	1.21	0.05
TOP	36	0.08	0.05	0.03	0.20	0.01
CU	36	0.32	0.17	0.16	0.80	0.28
PB	36	0.21	0.15	0.50	0.50	0.25
ZN	36	0.16	0.14	0.34	0.85	0.24
HG	3	0.24	0.02	0.22	0.26	0.01
SWEPT						
TS	11	534.82	466.26	86.23	1642.36	140.58
TSS	12	406.39	420.35	18.92	1483.19	121.35
BOD	2	20.25	17.89	7.60	32.90	12.65
COD	6	172.70	132.49	37.36	381.60	54.09
TKN	12	2.19	1.82	0.32	6.84	0.53
NH_3	12	0.49	0.47	0.02	1.57	0.14
NO_3	12	0.92	0.32	0.39	1.38	0.09
TP	12	0.76	0.60	0.11	1.98	0.17
TOP	12	0.17	0.20	0.02	0.76	0.06
CU	12	0.49	0.28	0.15	0.95	0.82
PB	12	0.38	0.33	0.51	0.88	0.97
ZN	12	0.25	0.19	0.59	0.59	0.54
HG	2	0.44	0.04	0.41	0.47	0.03

Table 9

Table 10

Comparison of Average Rainfall Inputs to Average Total Storm Load

Central Business District

(Watershed)

Pollutant	Average Rainfall Load (lbs.)	Average Event Load (lbs.)	% Difference *
TKN	1.04	3.34	33.3
NO_3	.79	2.26	38.7
TP	.098	.96	10.9
CU	.081	.22	43.4
PB	.19	1.29	24.2
ZN	.10	1.42	9.93
HG	.00074	.00205	39.7
Residential Study Area			
TKN	1.96	10.72	22.6
NO_3	1.76	5.77	42.6
TP	.20	5.18	4.54
CU	.12	.24	58.2
PB	.25	1.23	23.9
ZN	.14	.99	19.4

* % of total attributed to rainfall

BIOLOGICAL REVIEW

A biological review of the two watersheds (Figure 35) was conducted to determine what impacts were present, if any, on the macroinvertebrates. The benthic population was found to be extremely stressed due primarily to non-point runoff sources. Aquatic bioassays demonstrated acutely toxic conditions developing in receiving waters both between and during rain events. Almost all measured toxic conditions were associated with rainfall. Street sweeping activities were employed alternately in the two watersheds while the biological surveys and the bioassays were used to monitor ecosystem reaction. Toxic conditions still developed even with street sweeping employed on a five day per week basis in the watershed.

Species diversity values for Burk Branch (residential stream) and Salem Creek -1 (upstream control) generally indicated clean to moderately stressed conditions as illustrated in Figure 36. Tar Branch (CBD stream) and Salem Creek -2 (upstream control) indicated moderate to severe stress. Street sweeping had no effect on the species diversity of benthos in Tar Branch and only a speculative effect on the diversity in Burk Branch. Benke (et al. 1931) has suggested that a species diversity index may not be as sensitive as other indices in detecting the effects of urbanization.

A Biotic index has been used in many biological surveys conducted by the North Carolina Department of Natural Resources and Community Development's Division of Environmental Management (Penrose et al. 1980, Lenat et al., 1979), and has been more sensitive in many cases. The criteria assessment (from Hilsenloff, 1977) indicates the average index values are all in the poor to very poor classification (Figure 37). Again, with no apparent improvement due to the present street sweeping management practices.

Benthic Composition:

The composition of the benthic communities consisted almost entirely (90-100%) of tolerant groups such as the Oligochaeta and Diptera at all of the stations though particularly in Tar Branch and Salem Creek-2. Intolerant groups such as Ephemeroptera, Plecoptera and Trichoptera were more often present at Burk Branch and Salem Creek-1. Taxa richness for this group was low at all of the stations.

Oligochaeta were the most abundant at Salem Creek-2 which strongly indicates heavy organic loading. *Physa*, an indicator of low dissolved oxygen was also collected but only at Salem Creek-2. Chironomid data are often used to deduce both the degree and type of stress in lotic systems. Both Tar Branch and Salem Creek-2 showed an abundance of Chiromids which are associated with toxic conditions, especially metals. The species composition at Tar Branch is more characteristic of abundant periphyton growths which are possibly due to an open canopy and nutrient inputs.

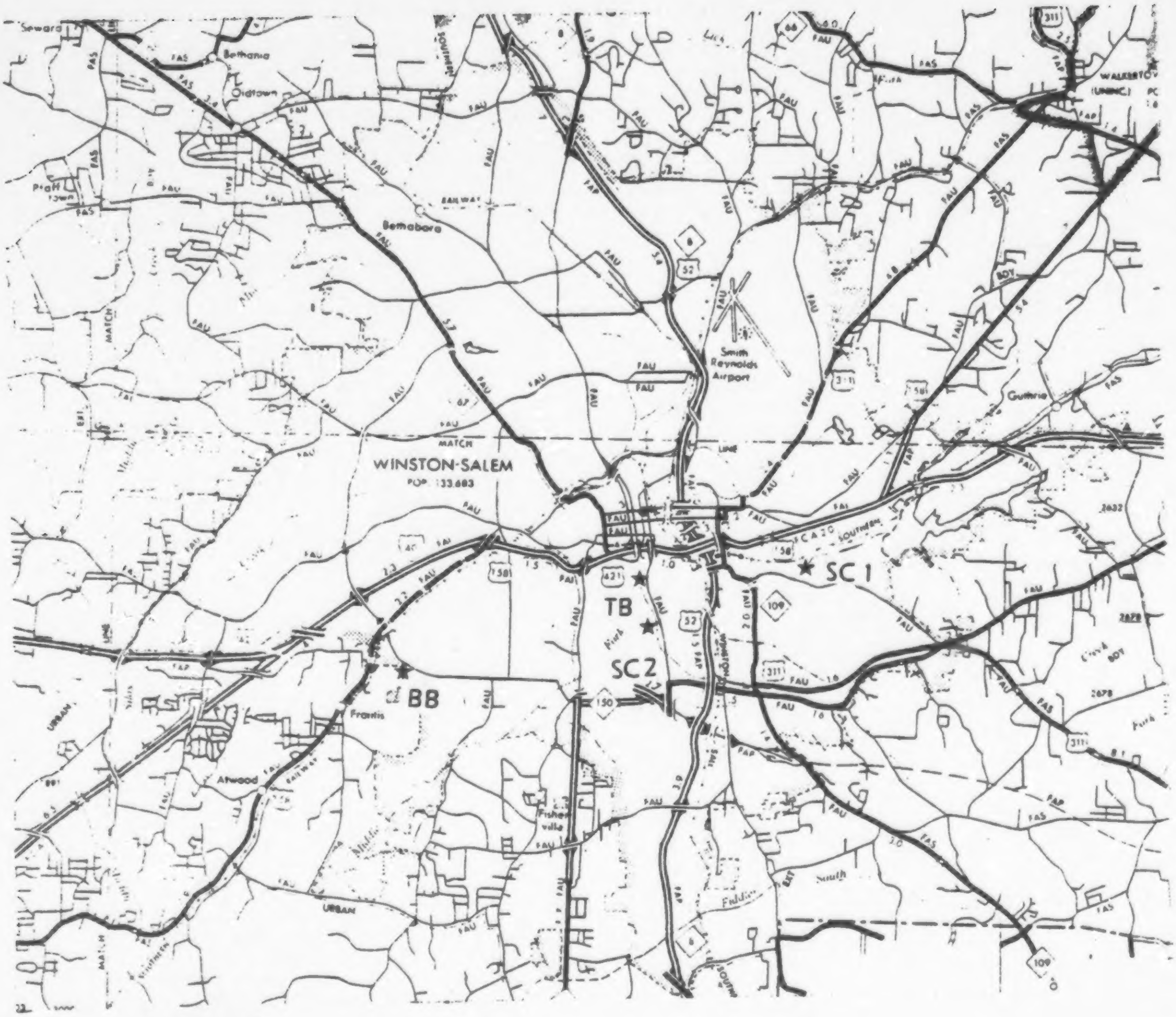
Sediment associated species are abundant at both Burk Branch and Salem Creek-1. Sedimentation is a problem at Burk Branch although taxa richness at all of the stations is well below that associated with a simple sediment problem. No rare or especially sensitive species were observed during the biological study. Street sweeping did not appear to demonstrate an impact on the composition of the benthic fauna in either the Tar Branch or Burk Branch watersheds.

Bioassays:

Twenty bioassays were performed using samples from the urban runoff. Ten were analyzed on creek samples taken between rain events and the other ten were performed on runoff samples taken during a rain event. Only two samples taken between rain events showed evidence of acute toxicity. All other tests revealed no statistical differences from the control tests. The Probit Analysis calculation using LC_{50} (lethal concentrations) concluded Burk Branch to have a value of 65% with confidence limits (95%) of 59.9 and 74.2%. The LC_{50} for Tar Branch was determined to be 55% with 95% confidence limits of 50.2 and 60.0%.

Figure 35

Biological Sampling Station Locations



Residential
- **BB-Burk Branch**

CBD
- **TB-Tar Branch**

Upstream Controls
- **SC1-Salem Creek (Site 1)**
- **SC2-Salem Creek (Site 2)**

Reproduced from best available copy.

Figure 36

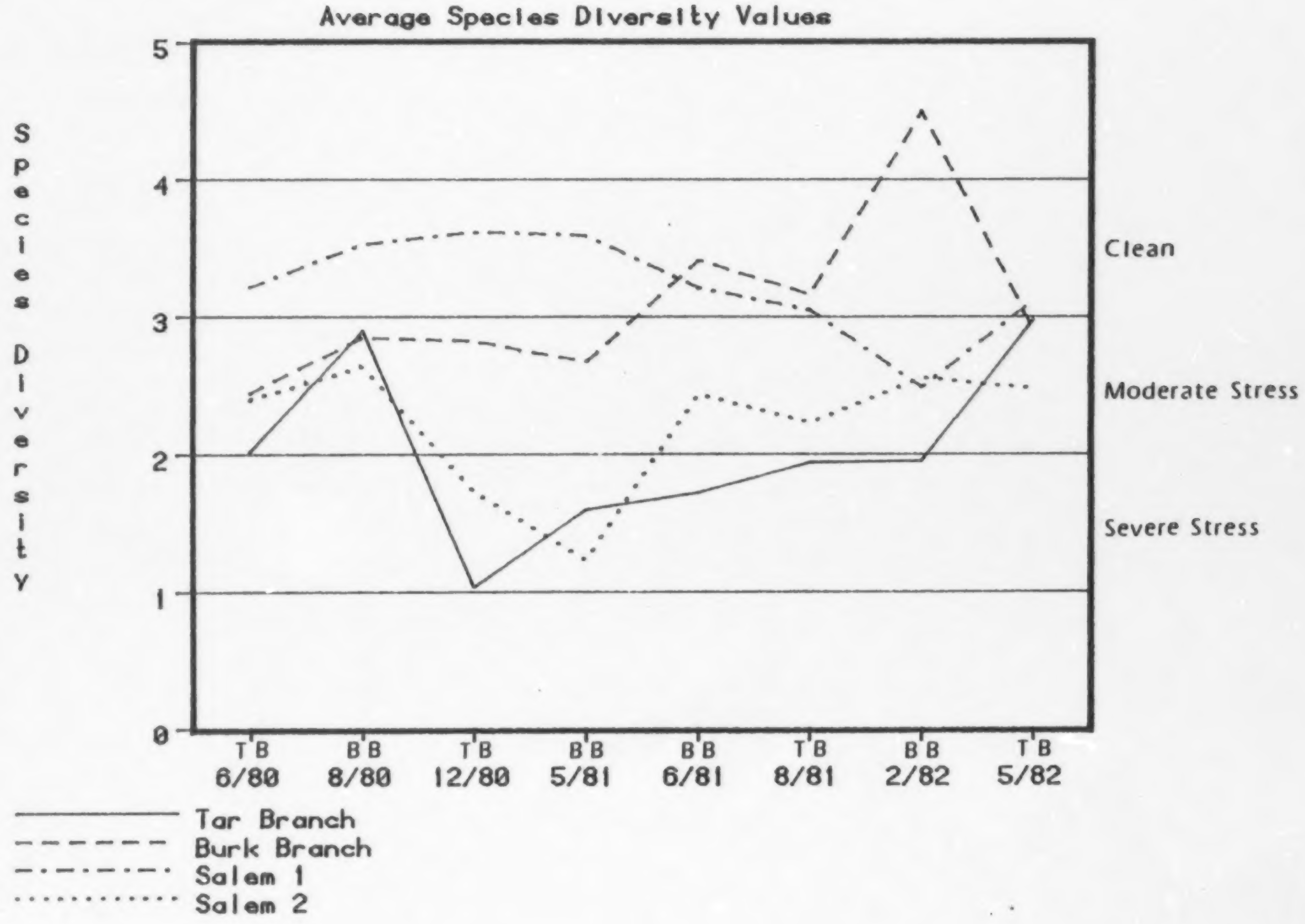
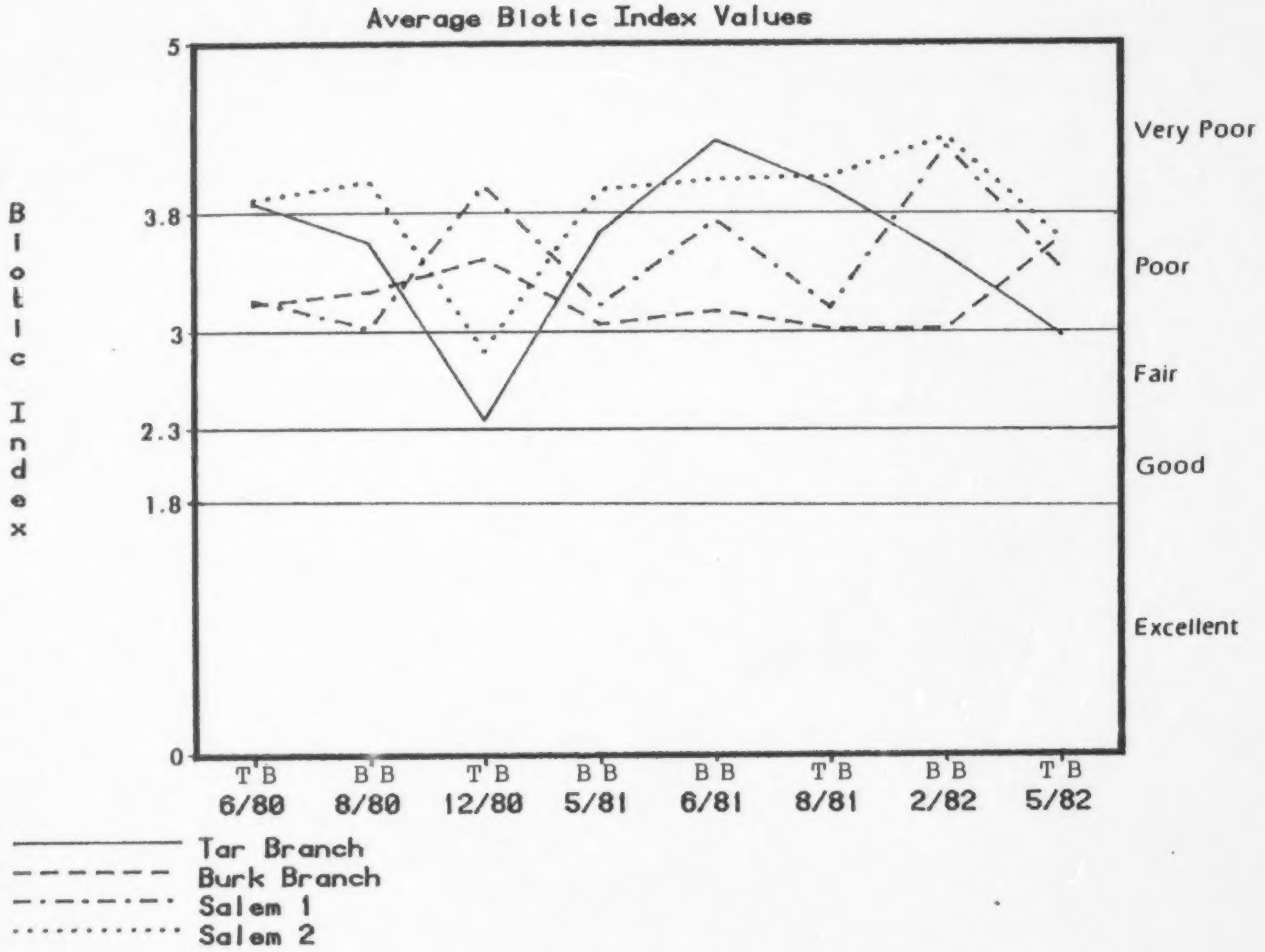

Average Species Diversity Values

Figure 37


Average Biotic Index Values
Biotic Index
5
3.8
3
2.3
1.8
0
Very Poor
Poor
Fair
Good
Excellent
T B
6/80
B B
8/80
T B
12/80
B B
5/81
B B
6/81
T B
8/81
B B
2/82
T B
5/82
Tar Branch
Burk Branch
Salem 1
Salem 2

Acute toxicity was measurable in six out of ten bioassays performed on stream water taken during rain events. There were no differences in frequency of measurable acute toxicity between first flush samples and composites. First flush samples constituted equal portions of the first 25% of the rain event. Composite samples were equal portions from all samples throughout the rain event. One rain event February 9, 1982, revealed no acute toxicity in either the first flush or the composite in Burk Branch (residential). However, the same rain event caused acute toxic conditions in Tar Branch (CBD). This condition was evident in the composite only and not within the first flush.

During a rain event on December 15, 1982, only runoff samples from the CBD were tested for toxicity. During this period sweeping activities had been implemented for this watershed. Acute toxicity levels were seen in both the composite and first flush samples.

COSTS SUMMARY

Cost information pertaining to the implementation of street sweeping activities as a best management practice (BMP) in two different watersheds was collected from July 1980 to May 1982.

The cost information was documented and assembled during the course of the NURP study on real world conditions since the study emphasis was to investigate control measures as employed in Winston-Salem, North Carolina. In determining feasibility of various practices in controlling street surface solids, this cost information was essential. Much care was taken to document all cost information such as equipment maintenance, repair and operational costs, administrative and managerial support costs, etc. These various cost factors were tracked with regard to their potential impacts on overall program costs as well. NURP study site sweeping costs were developed from cost invoices submitted to the project by the Street Cleaning Department. Since this department was reimbursed based upon these invoices, they were given adequate attention to ensure accuracy. As a part of cost documentation, overall street cleaning program costs were also documented. Cost information was developed from these sources on seasonal, mileage, and poundage bases. NURP BMP cost figures are compared to overall project costs (Normal Program Costs) in Table 11. A discussion of assumptions used to calculate these values is contained in the following paragraphs.

In the analysis of costs associated with operation of the street sweepers, total annual labor hours were developed by extrapolation of labor hours and miles associated with BMP implementation and total vehicle miles driven during the period. However, project activities account for various portions of the total mileage associated with sweeping efforts.

Several assumptions were made in order to develop annual operator cost values, which reflect sweeping activities as normally performed by the Winston-Salem Sanitation Division. Normal sweeping operations include sweeping some areas several times a week and sweeping other areas only occasionally (monthly or longer between sweepings).

•Assumptions employed include:

1) Eight (8) miles travel from the city yard to the cleaning areas, back to the city yard, and dumping, with cleaning of the hopper at the end of the day's shift. This activity was allocated as requiring one hour (time allocated includes time for vehicle operator to check oil and fuel vehicle at the shift's beginning).

2) Eight (8) miles travel and dumping of hopper content during the shift, requiring sixty (60) minutes. It was assumed that the hopper is emptied once during each shift, plus dumping hopper contents at the shift's end.

3) Total vehicle miles (non-project BMP miles) were allocated as 40% driven on the site (curb miles), with 60% of the mileage utilized in travel and dumping activities.

Such facts as cleaning frequency, distance to "cleaned" site, and disposal arrangements, can affect BMP costs on a unit as well as a total cost basis.

Also, costs are affected by differences between various pieces of equipment, because of down time, age, accidental abuse to individual equipment, etc. (Table 12). Since this type of equipment requires such a large capital investment, time of purchase (depreciation status) and finance charges can grossly affect the projected cost.

In general, the more units of equipment required and/or the larger the area to be cleaned, the less apparent are individual unit costs to the overall program costs.

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Table 11

Equipment Cost Differences*

Vehicle #	Cost/Cu-Mi Swept
4051	$11.64
4052	14.24
4053	5.00
4054	5.01
4055	5.46

* Example from Residential Land Use For Summer Season

Street Cleaning Costs ($)*

	CBD		Residential	
	Cost/#Solid Removed	Cost/Cu-Mi Swept	Cost/#Solids Removed	Cost/Cu-Mi Swept
Annual	.42	5.86	.21	10.13
Fall	.53	—	.31	10.78
Winter	.22	7.12	—	—
Spring	.57	5.95	.25	11.07
Summer	.72	5.15	.13	8.06

$15.45/cu-mile swept.

* Normal Program

TABLE 12

STREET SWEEPING COST SUMMARY (TOTAL PROGRAM)

Vehicle #	Vehicle Year/Type	Cost (Purchased)	Period (Months)	Depreciable Life Years	Total Cost For Period $	Calculated Hours of Operation	Miles Driven During Period	Avg. Hourly Operational Cost	Cost Curb-Mile
4050	1976 Int'l Vac All Sweeper	$61,776. (1977)	July, 1981-May, 1982 (11)	6	$31,658	874	3,264	$36.24	$16.07
4051	1977 Ford Tymco Sweeper	33,220. (1977)	July, 1980-May, 1982 (23)	5	49,266	1499	6,372	32.87	13.40
4052	1978 Ford Tymco Sweeper	36,575. (1978)	July, 1980-May, 1982 (23)	5	56,238	1611	5,348	34.91	22.71
4053	1980 Ford Tymco Sweeper	49,605. (1980)	April, 1980-May, 1981 (13)	5	33,961	1342.4	4,542	25.30	18.32
4054	1975 Ford Tymco Sweeper	21,988. (1975)	July, 1980-May, 1982 (23)	5	36,595	1945	6,833	18.81	11.12
4055	1975 Ford Tymco Sweeper	21,988. (1975)	July, 1980-May, 1982 (23)	5	25,509	866	4,033	29.46	13.91

TABLE 13

Cost Determinations Background Data

	CBD #'s of Street Solids Removed/Average Sweeping Trip	Residential #'s of Street Solids Removed/Average Sweeping Trip
Annual	83.7	1244
Fall	61	933
Winter	152	—
Spring	84.3	1037
Summer	37.4	1762

Watershed Area Information per Land Use

	CBD	Residential
Acerage	22.7	324.1
Curb-Miles	0.78	6.5
Street Surface	233,165	1,688,269

Street Solids Removal Data

	CBD		Residential	
	(#/Acre)	(#/Cu-Mi)	(#/Acre)	(#/Cu-Mi)
Annual	3.7	107	3.84	191
Fall	2.7	79	2.9	144
Winter	6.7	195	—	—
Spring	3.7	108	3.2	160
Summer	1.7	48	5.4	271

TABLE 14

Street Sweeping Cost Analysis by Activity

Vehicle	Sweeping Activity	Total Miles	Curb Miles Swept	Cost/Curb Miles Swept
4050	NURP Activity CBD	15	12	$ 2.69
	RES	-0-	-0-	-0-
	Regular Sweeping	3249	1958	16.15
4051	NURP Activity CBD	700	587	7.28
	RES	2838	1956	10.57
	Regular Sweeping	2834	1134	21.44
4052	NURP Activity CBD	161	130	9.38
	RES	991	668	11.94
	Regular Sweeping	4196	1678	28.03
4053	NURP Activity CBD	40	31	7.35
	RES	45	39	5.00
	Regular Sweeping	4457	1783	18.81
4054	NURP Activity CBD	803	648	19.22
	RES	581	461	4.93
	Regular Sweeping	5449	2180	18.72
4055	NURP Activity CBD	461	364	4.43
	RES	122	90	11.84
	Regular Sweeping	3450	1380	16.54

Table 13 contains information pertaining to various cost developed during this project. The more cost effective per pound of solids removed an equipment unit is, the higher are the sweeping costs per curb-mile swept. This relationship shows more cost-effective cleaning in areas with the higher street solids loadings. (Compare, for example, CBD-winter cost per pound to per curb-mile, or Residential-spring cost per pound to per curb-mile).

Also in Table 14, the average normal program cost was much higher than either the residential or CBD areas cleaned via the NURP study, even though the total program contained the same land use types as the study.

Since it costs approximately the same to move the street sweeper whether it is sweeping or not, non-sweeping transport of a sweeper is a noticeable expense. Further, this "hidden" cost multiplies with number of trips to the yard to empty the sweeper hopper. Therefore, this total program cost difference could exist due to higher costs incurred in transporting the street sweepers to other parts of the city at greater distances from the city garage than the NURP study sites. For instance, refer to vehicle N4051 (Table 4). Note that the smallest cost/curb mile figure is associated with the higher swept miles to total miles ratio, and this relationship hold in general. As well, since the city's normal program didn't sweep as frequently as the NURP BMP trail (daily), the street sweeper hopper became full more frequently; therefore, more frequent dumping was required. Increased dumping required more trips to and from the garage thus increasing costs.

Also, note the higher costs associated with cleaning the residential area than the CBD area (Table 11). Possible explanations include parking restrictions, operator difference, or degree of expected results. However, please note that the residential acreage is quite larger than the CBD acreage studied (Table 13). This size difference could allow transportation and repair costs to control the cost estimates since there are less curb miles associated with the CBD.

Another BMP investigated during the Winston-Salem NURP project was catch basin cleaning. The idea was to determine optimum cleaning frequency and associated costs. It was hoped that suggestions on possible improvements could be developed.

However, in Winston-Salem it was found that the city does not have an "real" catch basins. All of the outlet pipes are at the bottom of the pit. Therefore, any material that comes into the basin will leave unless it is larger than the outlet pipe or unless the pipe becomes clogged. This design, in fact, has gained popularity due to decreased maintenance costs.

The city has a routine and an emergency catch basin cleaning program. Every catch basin in the city is cleaned annually. Also, cleaning occurs in response to emergency calls; those calls associated with clogged catch basins.

Costs were taken from the normal program costs from Winston-Salem, and the cost per catch basin cleaned was $4.87. However, if a city has real catch basins designed to settle and trap solids the cleaning costs should be quite higher. These higher costs would be due to the probable increase volume of solids to remove, as well as the probable increased emergency cleaning trips. The catch basin cleaning study was greatly abbreviated due to the absence of "real" catch basins.

All cost information utilized in this discussion has been documented in a Forsyth County Environmental Affairs Department report entitled, "Final Cost Analysis for Street Sweeping Efforts in the Winston-Salem, North Carolina NURP Project." (Mr. Kirk Rife of that Department may be contacted for this or other cost information.)

DISCUSSION

The results showed that the accumulation of solids on the street levels off in one to two days at about 400 lbs/curb mile in the CBD and 600 lbs/curb mile in the residential area. Over 80% of the solids on the street are located on the portion of the street from the curb out into the street one foot. High concentrations of pollutants are associated with the solids which accumulate on the street. The highest concentrations of these pollutants are associated with the smallest particle sizes. However, these high concentrations are dampened because of the low amount of these small particle sizes actually in the street dirt. The particle size range from 45 microns to 1000 microns actually contains most of the pollutants on the street.

The street sweeper was most effective at removing the 45 micron and larger fraction sizes in both watersheds. This was consistent with this fraction's carrying most of the pollutant load. However the efficiency of the sweeper averaged 29% in the residential watershed for total weight removal of the 45 and larger size fractions as compared to an average of 42% for the CBD watershed. The lower removal efficiency for the residential area is attributed primarily to leaf litter and inaccessability due to curbside parking.

Rainfall analysis showed that the minimum inter-event dry period was 11 hours with an average of approximately 72 hours. There was only a 10% chance of the accumulation period between rain events exceeding eight days.The average amount of precipitation for each watershed per storm event was .51 inches in the CBD and .69 inches in the residential area. The maximum precipitation during the study period was 3.35 and 4.13 inches respectively per storm event. Only four metals were consistently detected throughout the whole study; copper, lead, mercury and zinc. Other parameters analyzed for and detected were: total solids, total suspended solids, biochemical oxygen demand, fecal coliform, nitrate/nitrite, ammonia, total phosphorus, and nitrogen. Cadmium, cobalt, chromium, nickel and manganese were also analyzed for but usually noted at being below detectable limits. In general, the pollutants associated with the rain events were areawide in nature and windroses indicated that in the hours immediately preceding the storm, winds were from the south regardless of the time of year. The average pollutant loading in the rainfall was:

CU = .0042 lbs/acre/storm event
ZN = .0053 lbs/acre/storm event
PB = .0011 lbs/acre/storm event
NH_3 = .0476 lbs/acre/storm event
TKN = .0556 lbs/acre/storm event
NO_2NO_3 = .0530 lbs/acre/storm event
Total P = .0050 lbs/acre/storm event

The water quality of the two watersheds was the central issue; what are the pollutant concentrations, are there exceedances of water quality standards, what do the biological indicators demonstrate and finally what effect does street sweeping have on water quality. Both watersheds receive substantial loadings of pollutants from not only land surface runoff but also atmospheric washout. The instream mean concentrations can be translated into frequency of occurrence curves to determine if there is a problem and how often it might occur. According to the graphs in the body of the report, certain parameters (central business district, organoleptic standard for copper) exceed EPA standards as often as once every three weeks or as little as ten times a year in the residential area for zinc. These graphs give a good idea of a watershed's overall water quality and can help agencies or planners determine if the frequency of occurrence is a problem. However when pollutant loading is considered on an acreage basis rather than by watershed, the central business district generated up to 310 times more loading per parameter (mercury, in this case) per acre-year than the residential area. The other parameters ranged from 2.66 for BOD to 15.42 for zinc. The parameters that showed the greatest difference between the residential area and the central business district were the metals, nitrite/nitrate and ammonia. The automobile traffic would account for the metal loadings primarily and leaky sanitary sewers would most likely account for the heavy organic loading. The effects of this type of runoff are reflected in the benthic communities. Sampling downstream of the CBD showed an abundance of species (Oligochaeta) that are associated with heavy organic loading and also Chiromids which are associated with toxic conditions, especially metals. Sediment associated species were found as more prevalent at the residential sampling site. In general, tolerant species were found in both watersheds but more abundant in the central business district, whereas the intolerant species were more often present in the residential area. However, the biological analysis showed degradation of the receiving streams in both watersheds.

While the results of the street sweeper efficiency tests showed a positive removal of street dirt and thereby pollutant removal from the street surface, no direct improvement in water quality could be shown as a result of the street sweeping program. This was true for all parameters tested in both study watersheds during all seasons. Several reasons may exist for the lack of success of the sweeping program. First is the ratio between the amount of surface area swept versus the total watershed area available for washoff. The sweeper is not capable of removing pollutant loadings from contributing sources other than streets such as the sidewalks, driveways, parking lots, rooftops, lawns and other related surfaces. These contributing sources may mask the sweeping effects. Second, atmospheric washout loading for some parameters may have contributed the bulk of the storm load. Whether the atmospheric pollutant loading is derived locally, being transported by the storms or both, the street sweepers are incapable of removing the pollutant loading before it enters the receiving streams. Third, a condition of "armoring" is possible. Armoring of the smaller fraction sizes (less than 45 microns) by the larger sizes occurs until the larger are removed by street sweeping which would make the smaller sizes more susceptible to washoff. Other sources of loading could be the sweeper due to brush wear, breakup of street solids into more and smaller sizes or street surface breakup due to brush agitation.

The ideal situation for improving water quality would be to eliminate or at least substantially reduce the amount of pollutants entering the aquatic environment through urban runoff. Several nonstructural local controls for minimizing pollutant loading are: stricter erosion control ordinances (controls on lot sizes smaller than an acre), limit traffic volume, elimination of salts or sands applied to highway surfaces, elimination of studded tires or chains, proper fertilizer and herbicide application, phosphate detergent control, proper litter and automobile lubricant disposal (recycle), car wash and filling station runoff control, control erosion from neglected property and pervious road surfaces, pet litter control, and sanitary sewer rehabilitation. In general "urban housekeeping" techniques which require very little capital investment and are practical. The purpose of these controls is reduction of pollutant loading, however total elimination is unlikely especially when atmospheric washout is considered, therefore structural controls to treat the runoff from the watershed as a whole working in conjunction with nonstructural methods are recommended. Several structural controls have been suggested as best management practices for improving urban runoff water quality. One of the foremost problems however is to incorporate these controls into an existing urban area. The unavailability or high cost of land is usually the prohibitive factor for locating structural controls in an urbanized area. The important consideration is to determine the extent or necessity of control and then weigh the "prohibitive" factors against the benefits.

Detention, retention basins and infiltration are best management practices that appear to be the most effective since they can work on a watershed basis. Other possibilities to help reduce the volume of runoff and the pollutant effects are grass swales, percolation pits and porous pavement. The type and size of the BMP are dependent on the geographical area and the type of parameters to be controlled.

New development has an advantage in managing runoff pollution by thoughtful planning for appropriate housing density; most importantly limiting impervious surface area, and implementing controls best suited for the area.

The Nationwide Urban Runoff Program offered insight into the effects of urban runoff and its extent along with the opportunity to test suggested best management practices to determine their effectiveness in order to make sound recommendations for future urban development.

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APPENDICES

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APPENDIX I

BIOLOGICAL REVIEW OF THE WINSTON-SALEM NATIONWIDE URBAN RUNOFF PROGRAM

Abstract

The biological review of several Winston-Salem, North Carolina watersheds reveal extreme impact upon the resident benthic macroinvertebrates. Stresses are due primarily to non-point runoff sources. Aquatic bioassays demonstrated acutely toxic conditions developing in receiving waters both between and during rain events. Almost all measured toxic conditions were associated with rainfall. Street sweeping activities were employed alternately in two watersheds while biological surveys and bioassays were used to monitor ecosystem reaction. Toxic conditions still developed with street sweeping being employed in the watershed. Sweeping activities were alternated too frequently to allow a biological reaction in stream invertebrate populations.

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INTRODUCTION

Background:

The biological monitoring group was asked by the Forsyth County Environmental Affairs Group to participate in the National Urban Runoff Program (NURP) being conducted in Winston-Salem. To determine effectiveness of management practices on stream biota, the group collected duplicate benthic macroinvertebrates samples from four sites quarterly, and conducted static bioassays at two sites.

There have been many recent surveys conducted on urban streams documenting impacts from a variety of point and/or non-point sources of pollution.

Urban nonpoint runoff may contain many toxic materials, especially heavy metals (Wilber and Hunter, 1979). Another source of toxic materials is the multitude of small, intermittent point sources which are characteristic of urban areas (Duda et al., 1979). Both the nonpoint and point sources will contribute "slug" doses of toxics which are difficult to measure with chemical monitoring.

Organic materials also may enter urban streams from a wide variety of point and nonpoint sources. Duda et al. (1979) described several areas where leaking sanitary sewer lines (often cross-connected with storm sewers) polluted urban North Carolina streams. This type of pollution is characterized by high coliform counts.

Urban streams are often stressed by sediment additions. This sediment may come directly from erosion of the surrounding land or indirectly from channel instability. Extensive paving of urban areas will lead to higher peak flows, and the resulting hydrologic instability often results in extensive bank erosion.

Several studies have documented the effects of urban runoff on stream benthos. Generally intolerant groups (Ephemeroptera, Plecoptera) are replaced by Chironomidae (DiGiano et al. 1975). Ali et al. (1977) studied the fauna of urban flood control channels. They found chironomid populations dominant in these highly artificial environments, with Cricotopus spp. making up 86% of the total fauna. Bradt (1978) found that urban runoff shifted community dominance first towards the Hydropsychidae and then towards the Chironomidae. It is interesting to note that this is the pattern predicted by Winner et al. (1980) for heavy metal pollution.

The most complete study of urban runoff was conducted on the Green River, Massachusetts (Pratt et al. 1981). Intolerant groups (Ephemeroptera, Plecoptera, Trichoptera) were replaced by chironomids, oligochaetes and gastropods. Total taxa richness for Ephemeroptera, Plecoptera and Trichoptera declined from 79 species at the control site to only 19 species at the most downstream site.

Klein (1979) related species diversity to the percentage of impervious area in urban waterseds. He found diversity depressed if % impervious area exceeded 15%. Loading rates of certain metals (Zn, Pb) also increased as watershed imperviousness increases.

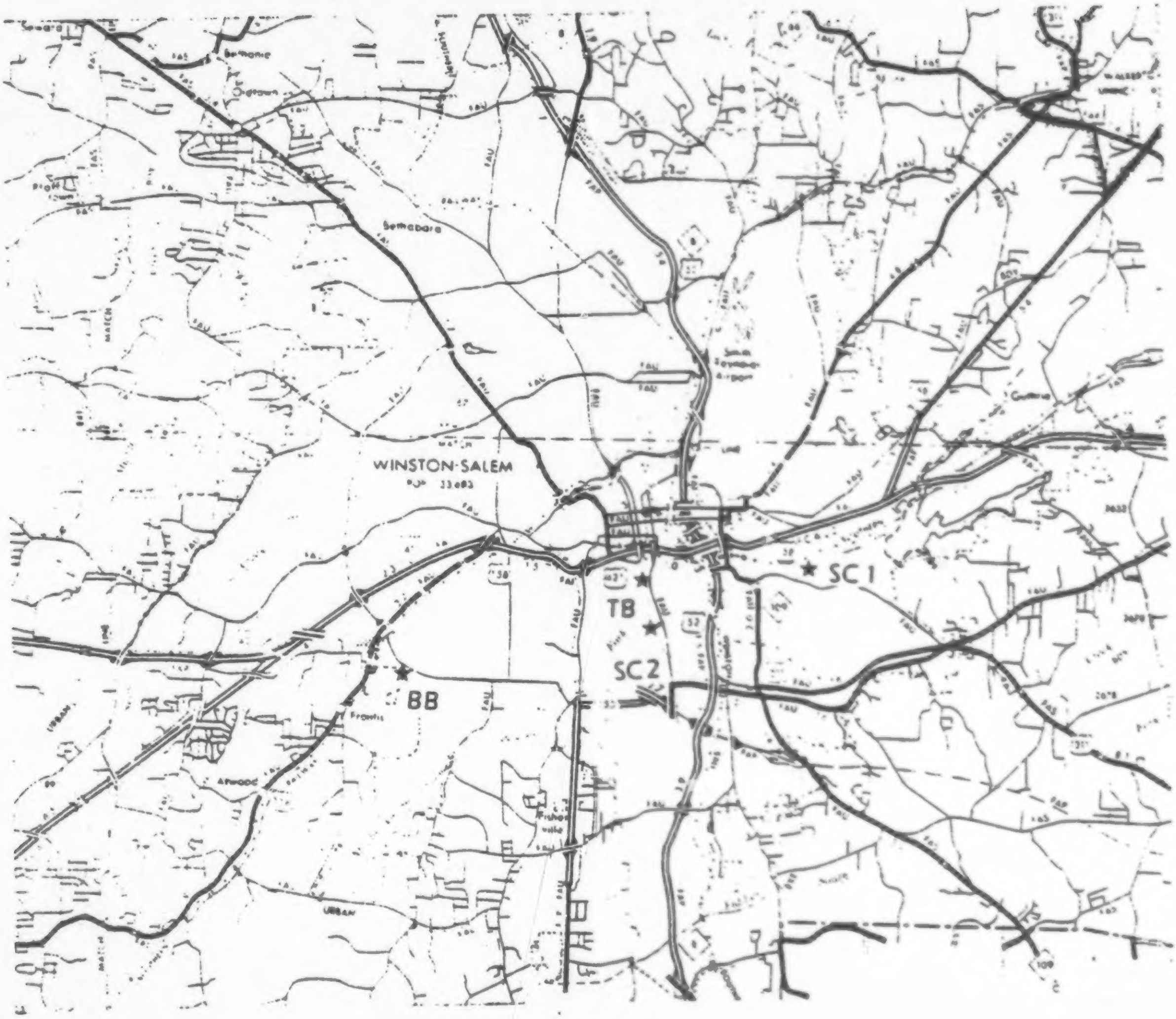
Objectives:

The objectives of this subtask of the program are to determine how current street sweeping practices affect the biological integrity of stream draining urban watersheds. Sampling stations were located in watersheds which were to have these management practices implemented.

The watersheds are: Tar Branch which is located within the central business district of Winston-Salem, Burk Branch which is located in a residential section of Winston-Salem and two stations on Salem Creek into which both Tar Branch and Burk Branch flow (see Figure 1).

Fig. 1

Sampling Station Locations



METHODS

Benthic Macroinvertebrates:

All benthic macroinvertebrate samples were collected by the "kick" method. A net is positioned upright on the stream bed, while an upstream area of one square meter is physically disrupted. The kicknet method of collecting benthic invertebrates is more advantageous in determining population composition than other collection methods such as Surber square foot, dip net, or core techniques (White and Fox, 1980). Duplicate samples were collected at each site. All samples were preserved in ethanol and returned to the laboratory for processing.

Three levels of data analysis are used (Penrose et al., 1980). The first level of data analysis emphasizes very general observations in community structure. Such observations include total taxa richness and organism abundance at each station. A species diversity and biotic index will be calculated to determine general community integrity. The second level of analysis will discuss community integrity. The second level of analysis will discuss community structure at a functional group level. The third level of analysis will discuss the results at the taxa or species level. Data at this level can often be used to deduce the nature of pollutants. Information on the pollution tolerance of any given taxon, combined with quantitative data on its distribution, can often be related to specific chemical and physical change in the environment.

Bioassay:

During the months of June, 1981, through March, 1982, a series of urban runoff bioassays were performed. A bioassay is a laboratory test procedure which exposes a hemogenous population of test organisms to an array of toxicant concentrations. Toxic levels can then be determined from the results. These tests used Daphnia pulex as a test organism to measure acute toxicities in the urban runoff components. The urban runoff tests were conducted on both Burk Branch and Tar Branch. Burke Branch was a stream receiving runoff from a residential area (Ardmore) with 27.7% impervious area and a watershed of 324.1 acres. Tar Branch is a stream receiving runoff from the Central Business District of Winston-Salem. It has 68.7% impervious area and a total watershed surface of 22.7 acres.

Daphnia pulex are found in ponds and sometimes in lakes (in contrast to some daphniads which are strictly pond or lake dwellers), although they probably could exist in any freshwater body with enough protection from preditors and supplied with sufficient food. The species covers most of North Carolina and is considered a sensitive test species which reflects a broad response to aquatic toxins.

Tests usually consist of five to seven concentrations of runoff as well as a control, each concentration done in replicate. At least ten *Daphnia pulex* (0-3 days old) are transferred under water in 10 ml of dilution water to each test vessel. Mortality is recorded at 24 and 48 hours. A toxicity curve is then constructed (Dose vs. Response) for comparison of test results.

RESULTS

Benthic Macroinvertebrates:

Figures 2-5 summarize the level I results of the benthic macroinvertebrate surveys conducted in Winston-Salem. The watershed receiving street sweeping is indicated on the horizontal axis below the date. Taxa richness values (Figure 2) are generally higher at Burk Branch (the residential watershed) and Salem Creek-1, and are normally much lower at Tar Branch (draining the central business district) and Salem Creek-2. Exceptions to the normally high taxa richness values at Salem Creek-1, were observed in March of 1981 (only one sample was collected) and again in February of 1982. These two occurrances do reflect local environmental disturbances. Low taxa richness at Tar Branch and Salem Creek-2 reflect the very poor water quality at these two sites.

The number of benthic invertebrates (Figure 3) was always much higher at Salem Creek-2 than at other stations. Low taxa richness and large numbers at this site reflect heavy organic loadings. These results do not change because of street sweeping activities in either Tar Branch or Burk Branch. Number of benthic invertebrates alone at the three other sites do not illustrate any improvement in water quality because of management activities in Burk Branch or Tar Branch.

Some particular taxa account for the large total numbers in Figure 3 (see level III results). For example, the mayfly _Baetis_ _flavistriga_ was extremely dominant in Burk Branch during the June, 1980 collection and the naiid Oligochaete _Pristina_ was extremely dominant in Tar Branch during the December 1980 collection. Both these observations can be related to flow, as little rainfall (cumulative totals for 2 weeks prior to collection in inches) was measured (0.49 for Burk Branch and 0.29 for Tar Branch.)

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Fig. 2

Total Taxa Richness of Benthic Macroinvertebrates

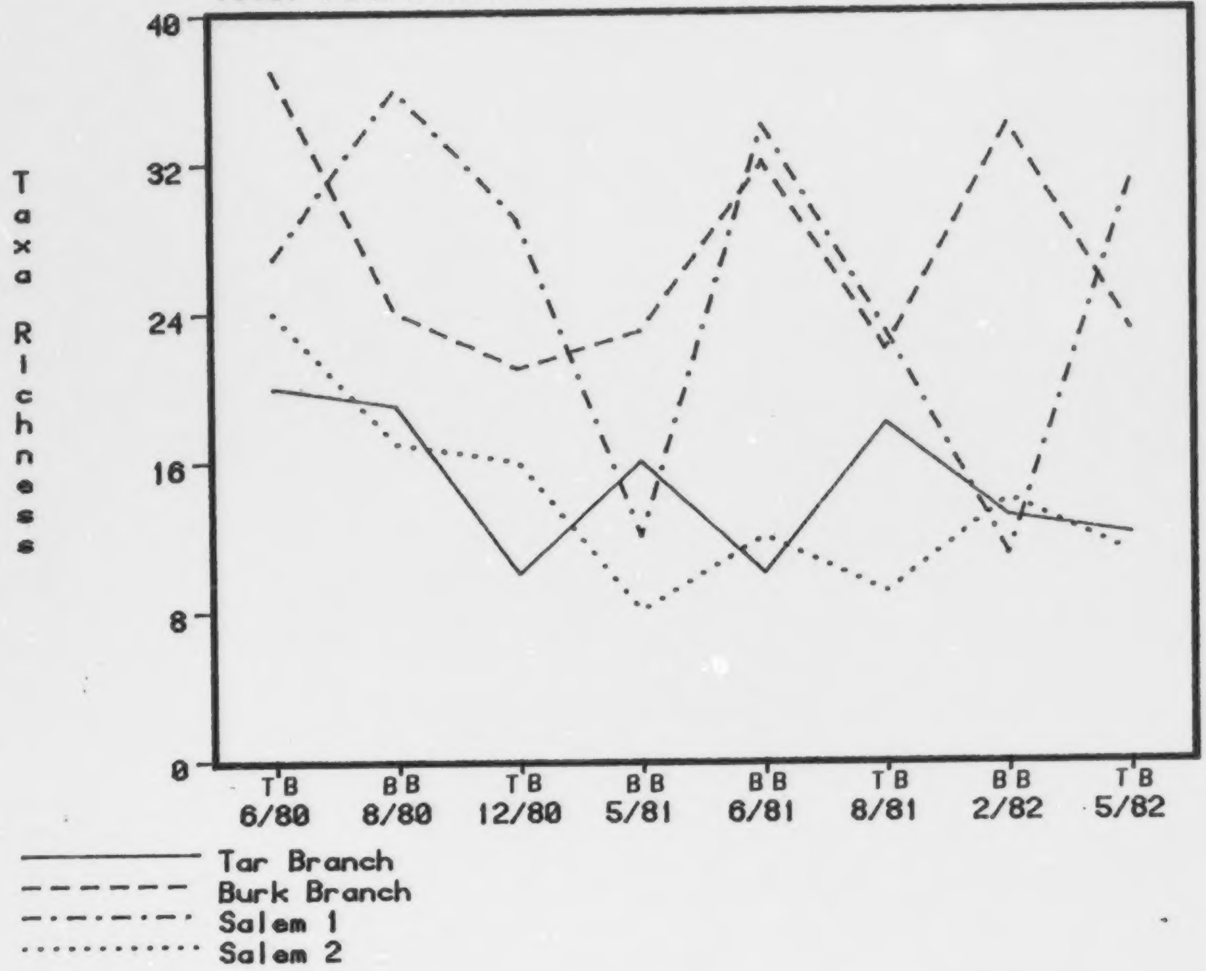
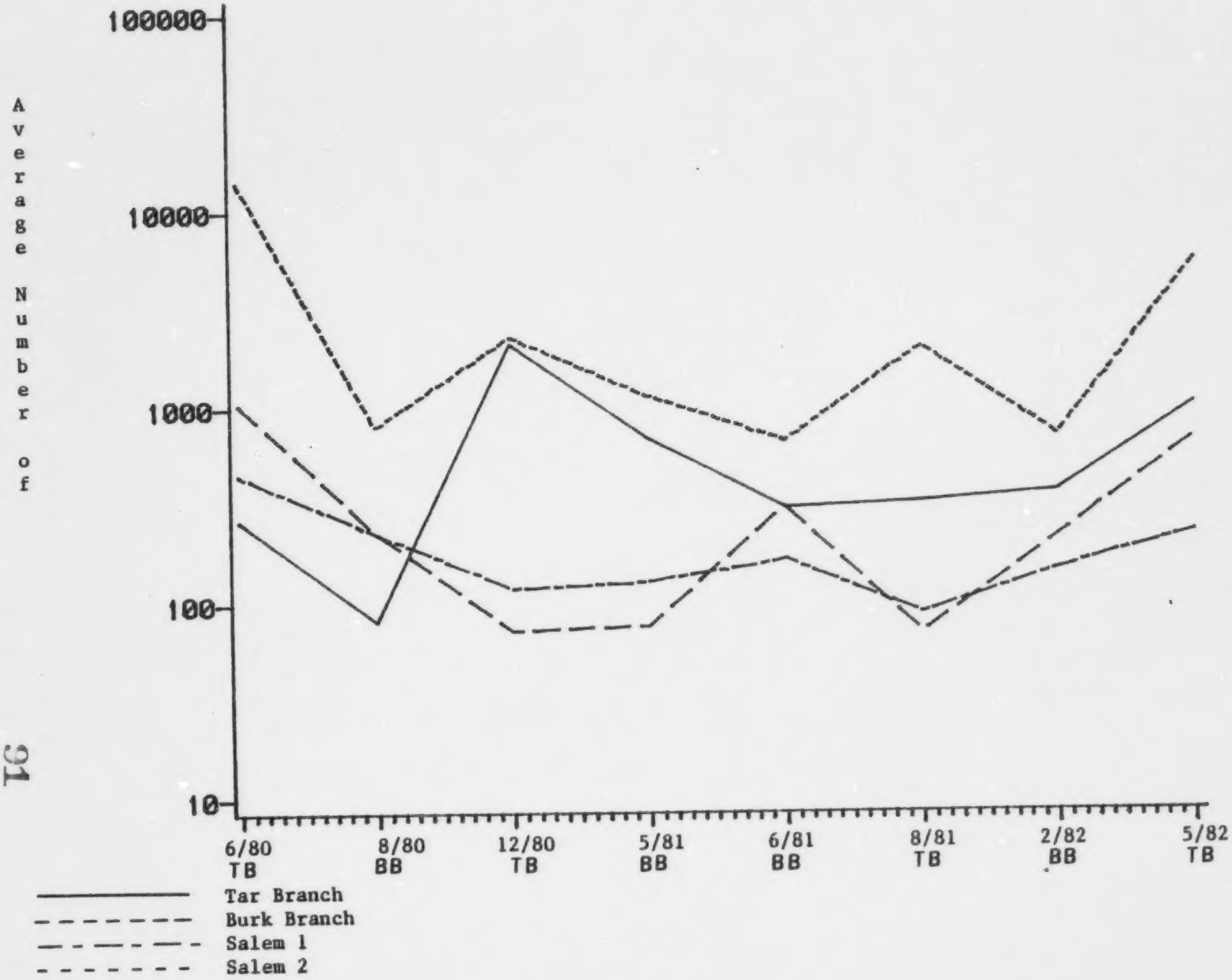


Fig. 3
Average Number of Benthic Macroinvertebrates



During these low flow periods, these taxa will repopulate rapidly; however, because of the unstable habitat in these streams, these populations did crash during the next spate event. Large rainfall totals are responsible for the decline in average number of invertebrates during September, 1980, and June, 1981, at Salem Creek-2.

Species diversity values (Figure 4) generally indicate clean to moderately stressed conditions at Burk Branch and Salem Creek-1 (0-2 severe stress; 2-3 moderate stress and 3-4 unpolluted: as of Wilhm, 1970). Moderate to severe stress is illustrated at Salem Creek-2 and Tar Branch. Street sweeping had no effect on the species diversity of benthos in Tar Branch and only a speculative effect on the species diversity of benthos in Burk Branch. A species diversity index however may not be as sensitive as other indices in detecting the effects of unbanization (Benke et al. 1981).

A biotic index has been used in many biological surveys conducted by the Division of Environmental Management (Penrose et al. 1980, Lenat et al, 1979), and has been more sensitive in many cases. The criteria for assessment are as follows (from Hilsenhoff, 1977): < 1.8 is excellent, 1.8-2.3 good, 2.3-3.0 fair, 3.0-3.8 poor and > 3.8 as very poor. Average biotic index values are all in the poor to very poor classification (Figure 5) with no apparent improvement because of management practices.

The second level of data analysis looks at community composition in more detail. Table 1 lists the percent abundance of Oligochaeta plus Diptera and Table 2 lists the percent abundance of Ephemeroptera plus

Plecoptera plus Trichopters. The Oligochaeta plus Diptera assembledge is comprized mostly of tolerant taxa while the Ephemeroptera plus Plecoptera plus Trichoptera assembledge is comprized mostly of intolerant taxa. The use of Ephemeroptera, Plecoptera and Trichoptera as functional groups in urban stream surveys was also used by Benke et al. (1981).

Fig. 4

Average Species Diversity Values

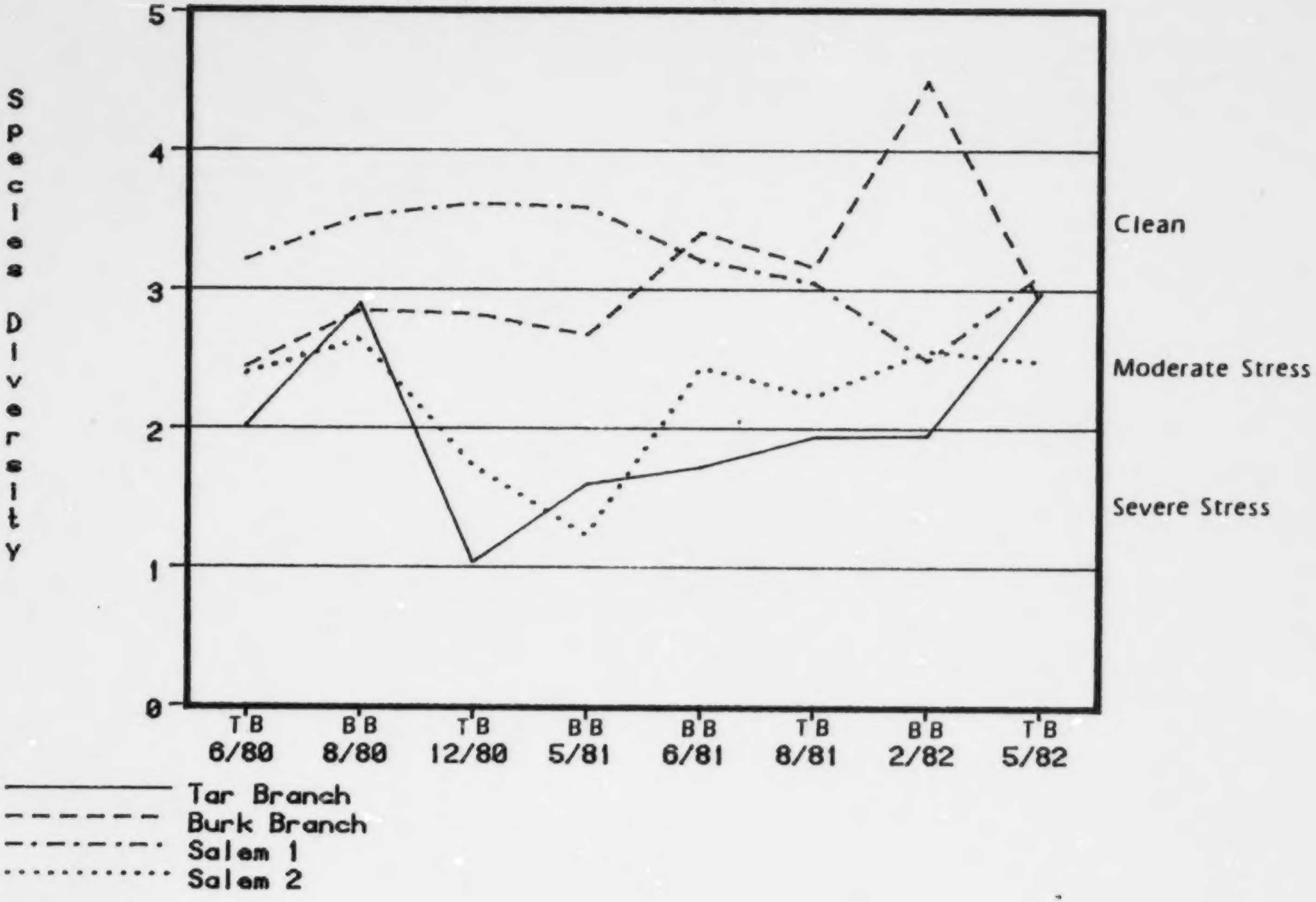


Fig. 5

Average Biotic Index Values

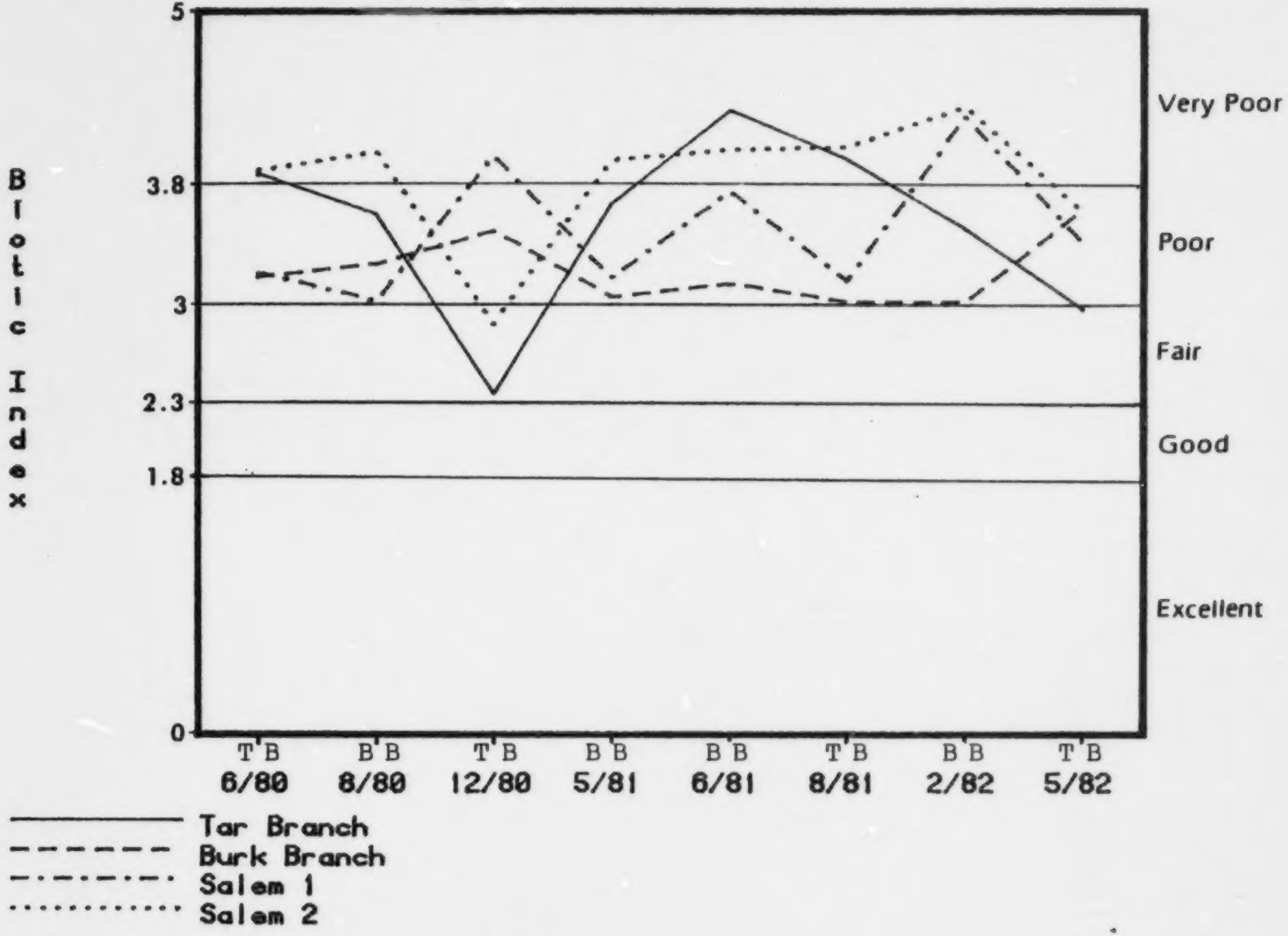


Table 1. Percent Abundance of Oligochaeta and Diptera From Tar Branch (TB), Burk Branch (BB), Salem Creek-1 (SC-1) and 2 (SC-2). NURP

	TB	BB	SC-1	SC-2
24 June 1980 (TB)	99	43	86	90
24 Sept 1980 (BB)	98	67	50	97
15 Dec 1980 (TB)	100	90	88	100
18 Mar 1981 (BB)	100	95	79	100
10 June 1981 (BB)	99	61	83	99
23 Sept 1981 (TB)	100	75	36	100
25 Feb 1982 (BB)	100	90	93	83
18 May 1982 (TB)	100	95	97	100

Table 2. Percent Abundance of Ephemeroptera plus Plecoptera plus Trichoptera from Tar Branch (TB), Burk Branch (BB), Salem Creek-1 (SC-1) and 2 (SC-2). NURP

	TB	BB	SC-1	SC-2
24 June 1980 (TB)	1	56	14	2
24 Sept 1980 (BB)	2	26	40	1
15 Dec 1980 (TB)	-	1	9	-
18 Mar 1981 (BB)	-	1	12	-
10 June 1981 (BB)	1	33	14	-
23 Sept 1981 (TB)	-	18	55	-
25 Feb 1982 (BB)	-	-	-	-
18 May 1982 (TB)	-	4	2	-

comprized mostly of tolerant taxa while the Ephemeroptera plus Plecoptera plus Trichoptera assembledge is comprized mostly of intolerant taxa. The use of Ephemeroptera, Plecoptera and Trichoptera as functional groups in urban stream surveys was also used by Benke et al. (1981).

Despite the fact that there were large differences in total abundance, percent abundance of tolerant groups were always high (mostly 90-100%) particularly in Tar Branch and Salem Creek-2. Intolerant groups appeared more often at Burk Branch and Salem Creek-1. The street sweeping activities in Tar Branch and Burk Branch watersheds (as indicated within the parenthesis for each date) appear to have little impact on the composition of the benthic fauna of either tributary or Salem Creek. An increase in percent abundance of intolerant taxa during the March-June collection periods coincided with the overlap period of management in Burk Branch. This may mean that there was an improvement in water quality in Burk Branch during this extended management period. Increases were also noted for taxa richness (Figure 2) and average density (Figure 3) in Burk Branch during this period. However, this apparent improvement may also be related to other environmental conditions (such as rainfall) or biological cycles.

Appendix I presents data (total # collected/taxa/station) at the level of individual taxa. This data can be used in several ways. First, examination of total species richness (in comparison to a control) helps to determine levels of stress. Selected data from Fourmile Creek (Lenat et al. 1979) is utilized as a control. This latter data set underestimates taxa richness (due to the greater taxonomic precision and sampling intensity utilized in the Winston-Salem study), but it helps to put the urban stream data in perspective.

The first section of Appendix I presents information on the most intolerant groups: Ephemeroptera, Plecoptera and Trichoptera. Taxa richness for this group was low at all stations; these organisms are largely absent at Tar Branch and Salem Creek-2. The most hardy members of these groups may be sporatically abundant at Burk Branch or Salem-2 (Baetis flavistriga, Stenonema modestum, Cheumatopsyche sp.). No rare or especially sensitive species were recorded during this study.

Facultative and miscellaneous groups are generally low in numbers and diversity. Physa, an indicator of low dissolved oxygen, was collected only at Salem Creek-2. The LC_{50} value for Burk Branch during July, 1981, was 65%. The confidence limits (95%) for this value are 57.9 and 74.2. At a higher level of toxicity Tar Branch had an LC_{50} value of 55% with 95% confidence limits of 50.2 and 60.0%.

Probit analysis is a standard analytical tool used to analyze quantal biological responses to specific stimuli or toxins. Two table types are presented within this document as test result summaries. One type is a graphical representation of the dose-response curve. Response values (on a scale of 0-1) are on the vertical axis with dosages (Percent) on the horizontal axis. The second table gives concentrations at which certain percentages of the test population will die (lenthal concentration). The most frequently used level of mortality for comparison purposes is the concentration which causes fifty percent mortality. This value is annotated as LC_{50}.

Tolerant groups (Diptera and Oligochaeta) dominate all all stations. Note that not all members in these groups are tolerant.

Chironomid data can be used to deduce both the degree and type of stress in lotic systems. Tar Branch and Salem Creek-1 are both dominated by Chironomids associated with toxic conditions, especially metals. These species include *Cricotopus bicinctus* (C/O sp 1), *C. tremulus* gr (C/O sp. 5, C/O sp. 6) *Conchapelopia* group and *Polypedilum illinoense*.

Sediment-associated species are abundant at both Burk Branch and Salem Creek-1. Heavy sedimentation appears to be a major problem at Burk Branch, although taxa richness at *all* stations is well below that associated with a simple sediment problem.

The Oligochaeta contain many species associated with organic pollutants and low dissolved oxygen conditions. This includes species associated with depositional areas (*Limnodrilus* spp., *Tubifex tubifex*) and epifaunal species associated with trickling filters (*Nais*, *Pristina*). The abundance of these taxa at Salem Creek-2 strongly indicates heavy organic loading. The species composition at Tar Branch is more characteristic of abundant periphyton growths, possibly due to nutrient inputs and an open canopy.

Changes in species composition could not be related to the use of management practices in either Burk Branch or Tar Branch.

Bioassay:

The results of the series of acute bioassays are summarized in Table 3. Twenty bioassays were performed using urban runoff. Ten were done on creek samples taken between rain events and ten were performed using runoff samples collected during a rain event. Of the ten tests conducted between rain events only two showed evidence of acute toxicity (7/16/81) in both Tar and Burk Branch. All other tests revealed no statistical differences from the control tests. Tables 4 through 7 depict the dose response curves and Probit Analysis calculations of these two positive tests.

Table 3. Urban Runoff Bioassay Summary

(M/P/Y) Date	(Residential) Burk Branch	(C.B.D.) Tar Branch	Sweeping	Acute Toxicity
Between Rain Events				
7/1/81	X		Yes	Neg
7/1/81		X	No	Neg
7/16/81	X		Yes	Pos (LC_{50}=65%)
7/16/81		X	No	Pos (LC_{50}=55%)
9/15/81	X		No	Neg
9/15/81		X	Yes	Neg
10/13/81	X		No	Neg
10/13/81		X	Yes	Neg
11/13/81	X		No	Neg
11/13/81		X	Yes	Neg
During Rain Event				
12/15/81		X(Composite)	Yes	Pos (LC_{50}-72%)
12/15/81		X(First Flush)	Yes	Pos (Irregular Data)
2/9/82	X(First Flush)		Yes	Neg
2/9/82	X(composite)		Yes	Neg
2/9/82		X(First Flush)	No	Neg
2/9/82		X(Composite)	No	Pos(LC_{50}=35%)
3/31/82	X(composite)		No	Neg
3/31/82	X(First Flush)		No	Pos(LC_{50}=70%)
3/31/82		X(Composite)	Yes	Pos(LC_{50}=67%)
3/31/82		X(First Flush)	Yes	Pos(LC_{50}=76%)

Table 4

DATA ANALYSIS BURK BRANCH JULY 16 1981

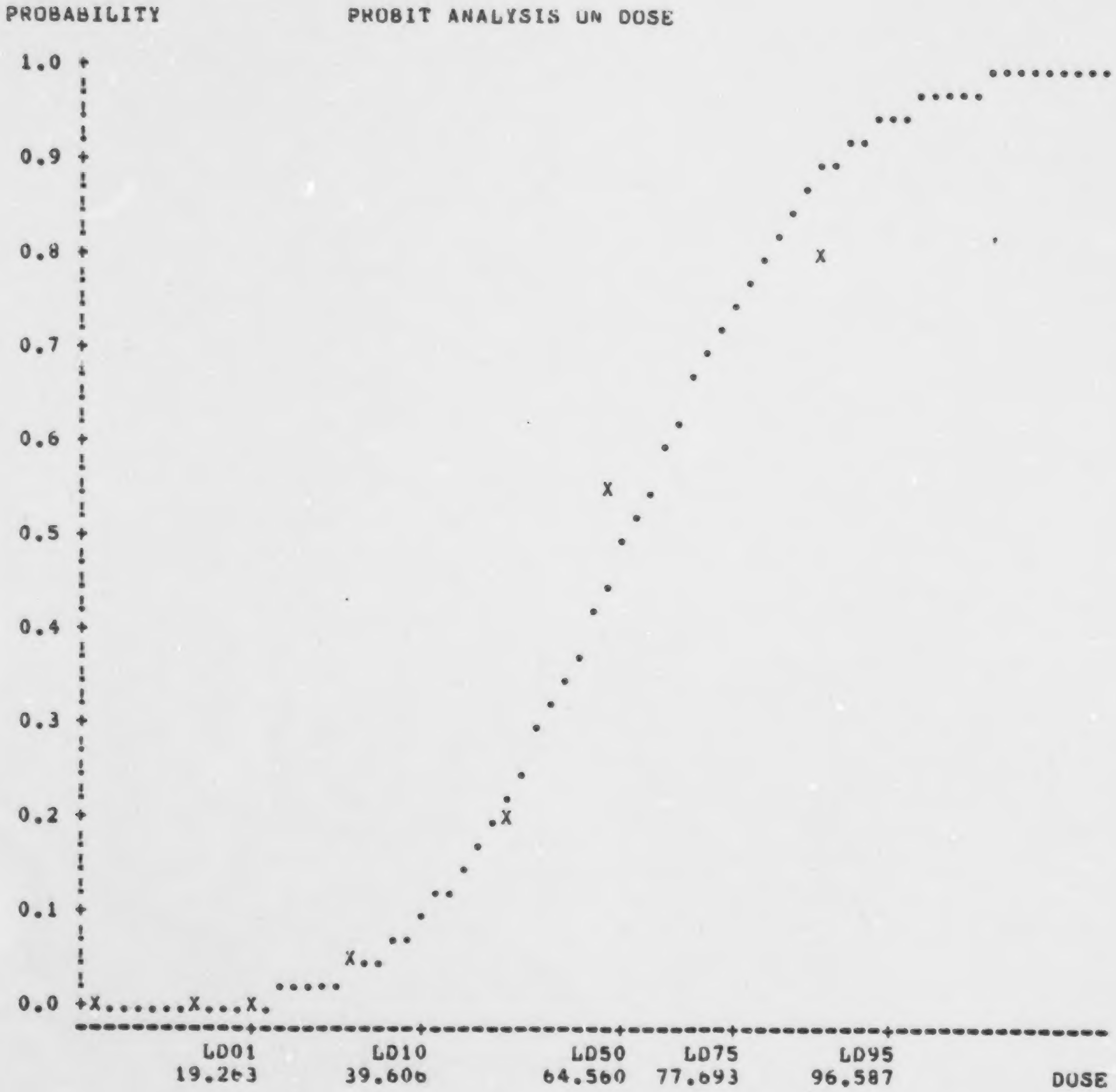


Table 5

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                DATA ANALYSIS BURK BRANCH JULY 16 1981


                      PROBIT ANALYSIS ON DOSE

 PROBABILITY              DOSE             95 PERCENT FIDUCIAL LIMITS
                                                LOWER             UPPER

    0.01              19.26281095           -3.24266024        30.50525806
    0.02              24.57065687            4.91568477        34.62665919
    0.03              27.93831494           10.05244351        37.28100568
    0.04              30.47167292           13.88984383        39.30455033
    0.05              32.53236421           16.99026655        40.97155420
    0.06              34.28633615           19.61148358        42.40816600
    0.07              35.82422642           21.89413273        43.68343890
    0.08              37.20122373           23.92375130        44.83951518
    0.09              38.45354769           25.75640804        45.90412045
    0.10              39.60631395           27.43093059        46.89653232
    0.15              44.37907425           34.20600269        51.16328129
    0.20              48.17231284           39.35066355        54.79430978
    0.25              51.42657380           43.53847599        58.13525740
    0.30              54.34900072           47.08801400        61.34677860
    0.35              57.05706478           50.18523132        64.51469025
    0.40              59.62675276           52.95550740        67.68940890
    0.45              62.11295561           55.49160940        70.90515809
    0.50              64.55974066           57.86635003        74.19107523
    0.55              67.00652571           60.13980611        77.57827691
    0.60              69.49272857           62.36473366        81.10520055
    0.65              72.06241654           64.59169851        84.82323043
    0.70              74.77048061           66.87508197        88.80497593
    0.75              77.69290752           69.28187814        93.15923898
    0.80              80.94716848           71.90781313        98.06206406
    0.85              84.74040707           74.91406736       103.83149917
    0.90              89.51316738           78.63531733       111.15207026
    0.91              90.66593363           79.52610490       112.92821712
    0.92              91.91825760           80.49085720       114.86072682
    0.93              93.29525491           81.54838130       116.98889757
    0.94              94.83314518           82.72577631       119.36942463
    0.95              96.58711712           84.06430114       122.08872861
    0.96              98.64780840           85.63166317       125.28879319
    0.97             101.18116638           87.55172418       129.22967715
    0.98             104.54882445           90.09414607       134.47836048
    0.99             109.85667037           94.08250655       142.76974615
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Table 6.

DATA ANALYSIS TAR BRANCH JULY 16 1981

PROBIT ANALYSIS ON DOSE

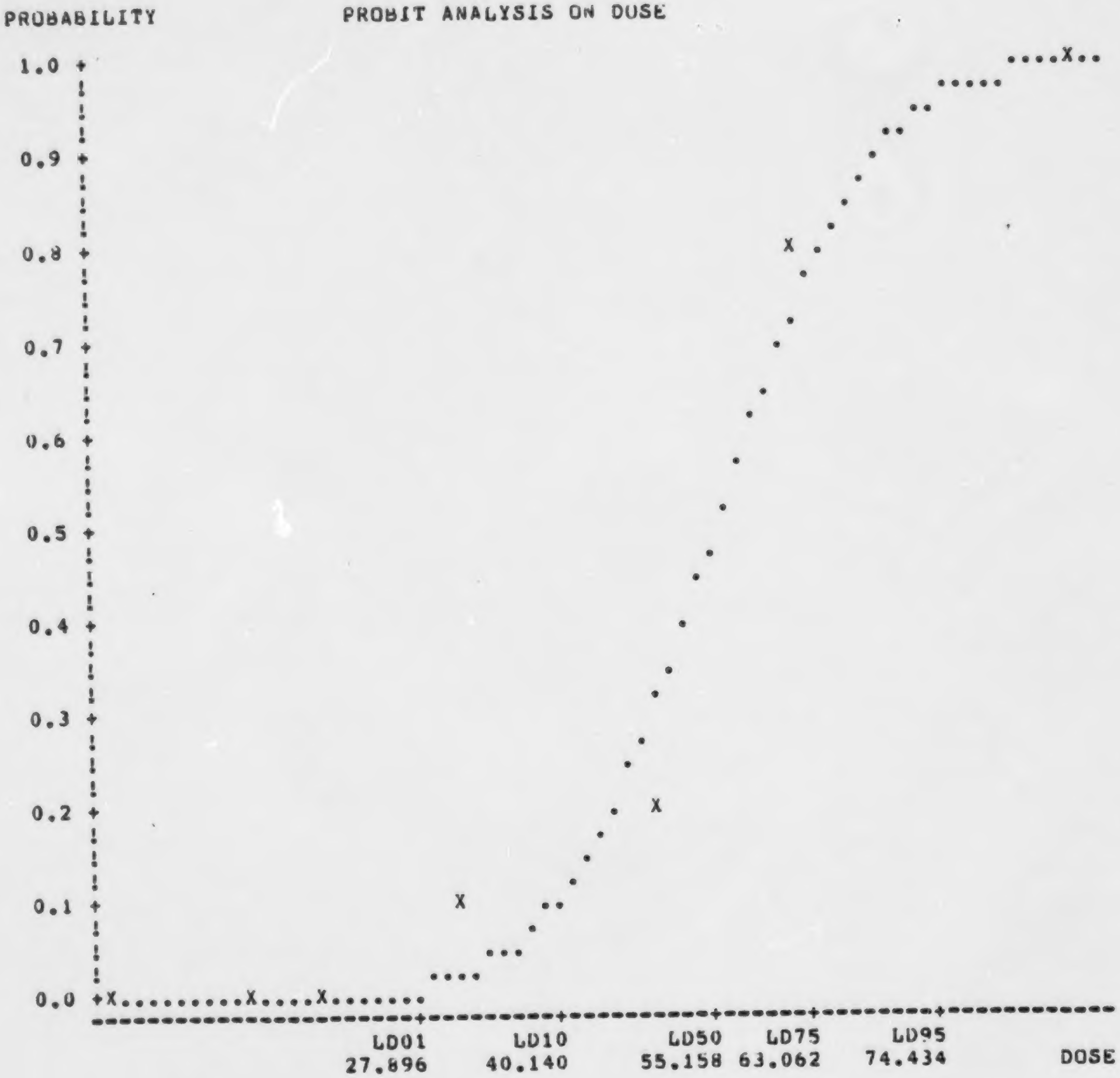


Table 7

DATA ANALYSIS TAR BRANCH JULY 16 1981

PROBIT ANALYSIS ON DOSE

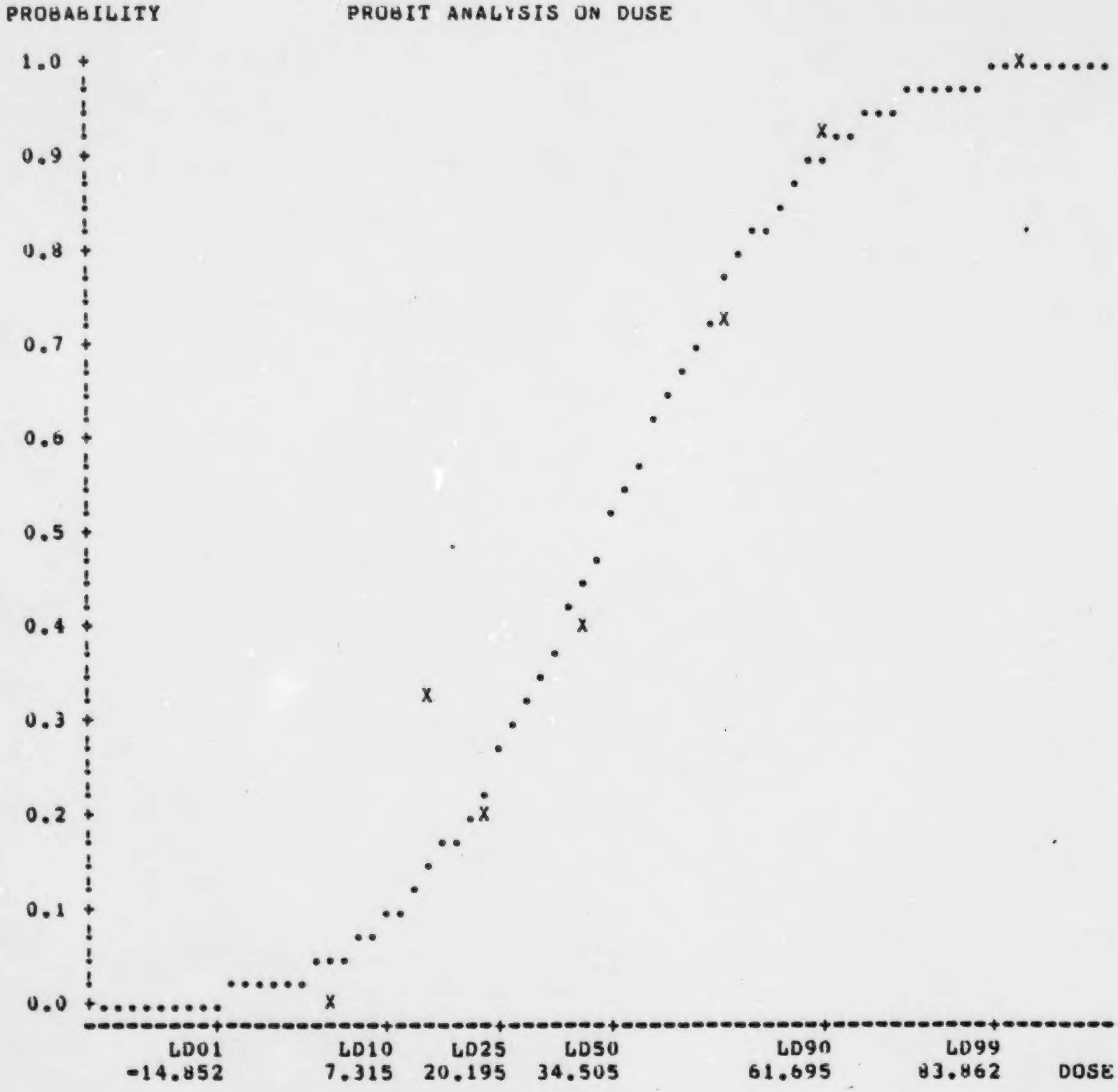
PROBABILITY	DOSE	95 PERCENT FIDUCIAL LIMITS LOWER	UPPER
0.01	27.89587488	6.43343476	36.86090276
0.02	31.09041424	11.98809953	39.19882459
0.03	33.11724704	15.49671858	40.69779869
0.04	34.64195440	18.12585133	41.83568321
0.05	35.88218623	20.25659237	42.76912011
0.06	36.93781830	22.06368237	43.57012681
0.07	37.86340112	23.64249163	44.27810814
0.08	38.69215014	25.05104623	44.91710177
0.09	39.44586421	26.32739561	45.50291558
0.10	40.13965925	27.49789845	46.04653702
0.15	43.01215609	32.28867626	48.35269166
0.20	45.29512552	36.01016675	50.27161811
0.25	47.25371001	39.11537301	52.00538735
0.30	49.01257942	41.81040291	53.65590701
0.35	50.64243405	44.20586549	55.28724371
0.40	52.18900670	46.36827704	56.94587089
0.45	53.68533365	48.34260267	58.66844446
0.50	55.15793689	50.16405071	60.48528267
0.55	56.63054014	51.86470254	62.42291710
0.60	58.12686708	53.47706578	64.50745306
0.65	59.67343974	55.03597507	66.76958250
0.70	61.30329437	56.58041353	69.25194332
0.75	63.06216377	58.15713472	72.02077169
0.80	65.02074827	59.82906327	75.18781865
0.85	67.30371769	61.69617633	78.96112252
0.90	70.17621453	63.95814481	83.79608649
0.91	70.87000958	64.49358616	84.97476942
0.92	71.62372365	65.07136622	86.25915255
0.93	72.45247267	65.70242923	87.67563777
0.94	73.37805549	66.40252737	89.26233022
0.95	74.43368756	67.19562166	91.07733263
0.96	75.67391938	68.12100201	93.21613022
0.97	77.19862675	69.25049248	95.85365702
0.98	79.22545955	70.74034826	99.37139439
0.99	82.41999891	73.06736397	104.93696528

Acute toxicity was measurable in six out of ten bioassays performed on stream water taken during rain events. There were no differences in frequency of measurable acute toxicity between first flush samples and composites. First flush samples constituted equal portions of the first 25% of the rain event. Composite samples were equal portions from all samples throughout the rain event. One rain event February 9, 1982, revealed no acute toxicity in either the first flush or the composite in Burk Branch (Residential). The same rain event however caused acutely toxic conditions to develop in the Central Business District (Tar Branch). This condition was evident in the composite sample only and not within the first-flush. Tables 8 and 9 depict the dose response curve and calculated LC_{50} value of 35%.

During a rain event December 15, 1982, only runoff samples from the Central Business District were tested for toxicity. During this period sweeping activities had been implemented in this watershed. Acute levels of toxicity were seen in both composite and first flush samples.

Table 8

DATA ANALYSIS CBD-COMPOSITE FEB 9,1982



PROBIT ANALYSIS ON DOSE

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Table 9

DATA ANALYSIS CBD-COMPOSITE FEB 9,1982

PROBIT ANALYSIS ON DOSE

PROBABILITY	DOSE	95 PERCENT FIDUCIAL LIMITS LOWER	UPPER
0.01	-14.85152109	-33.46313692	-3.71448470
0.02	-9.06795872	-25.64865920	0.99241449
0.03	-5.39847382	-20.71468194	4.00284942
0.04	-2.63806327	-17.01874955	6.28318887
0.05	-0.39268223	-14.02434068	8.15001610
0.06	1.51848969	-11.48545587	9.74880673
0.07	3.19421360	-9.26783224	11.15911503
0.08	4.69462449	-7.28977630	12.42943942
0.09	6.05918816	-5.49771347	13.59164855
0.10	7.31527126	-3.85452366	14.66787090
0.15	12.51579089	2.86946288	19.20297732
0.20	16.64899903	8.09543584	22.92537451
0.25	20.19492359	12.46672508	26.23099010
0.30	23.37927343	16.28158206	29.31023090
0.35	26.33004812	19.70622680	32.27399519
0.40	29.13004475	22.84642130	35.19577614
0.45	31.83907389	25.77760866	38.12962018
0.50	34.50515240	28.55959311	41.11967927
0.55	37.17123090	31.24458111	44.20673481
0.60	39.88026004	33.88237355	47.43397376
0.65	42.68025667	36.52485461	50.85346814
0.70	45.63103136	39.23155879	54.53517300
0.75	48.81538121	42.07878433	58.58204524
0.80	52.36130577	45.17759209	63.16014230
0.85	56.49451391	48.71615192	68.56995263
0.90	61.69503353	53.08558975	75.45960776
0.91	62.95111663	54.13015158	77.13445809
0.92	64.31568031	55.26094837	78.95793326
0.93	65.81609120	56.49994752	80.96731444
0.94	67.49181510	57.87880011	83.21639377
0.95	69.40298703	59.44569317	85.78717616
0.96	71.64836806	61.27970004	88.81440539
0.97	74.40877861	63.52546991	92.54490735
0.98	78.07826351	66.49791040	97.51687906
0.99	83.86182589	71.15874728	105.37741908

Tables 10 and 11 summarize the bioassay data for the composite sample bioassay. The first flush sample had irregular mortality between test concentrations with no mortality in the control test chambers. This could possibly have been due to physical impairment of the test organized by oils within the runoff sample. A "classic" toxic response may not have been expressed due to this confounding influence. The Daphnia became pinned against the air/water interface and died due to immobilization. The final rain event which was monitored March 31, 1982, had measurable toxic levels in all but the composite sample from Burk Branch. Tables 12 through 15 summarize these bioassays with the exception of the Burk Branch first flush. Due to the lack of partial mortality data points, the SAS system was unable to fit its model to this (Burk Branch first flush) date set. An approximate LC$_{50}$ value of 75% however is estimated.

Table 10

DATA ANALYSIS CBD-COMPOSITE DEC 15,1981

PROBIT ANALYSIS ON DOSE

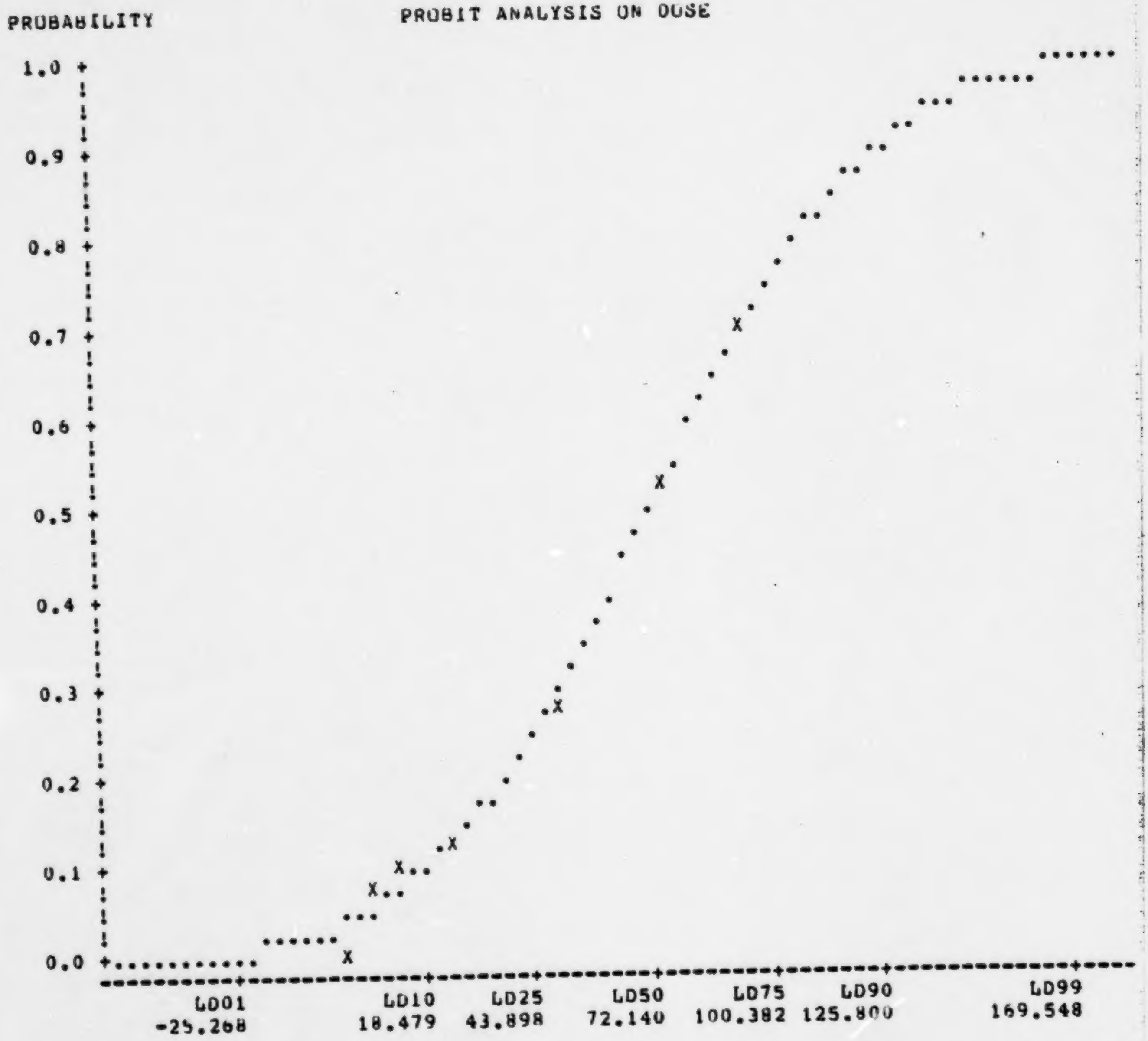

Table 11

DATA ANALYSIS CBD-COMPOSITE DEC 15,1981

PROBIT ANALYSIS ON DOSE

PROBABILITY	DOSE	95 PERCENT FIDUCIAL LIMITS	
		LOWER	UPPER
0.01	-25.26832819	-52.13075958	-8.48572910
0.02	-13.85415156	-37.16750837	0.92714847
0.03	-6.61222245	-27.72563467	6.95114695
0.04	-1.16440127	-20.65882525	11.51871074
0.05	3.26698100	-14.93922297	15.26277354
0.06	7.03878331	-10.09556080	18.47417673
0.07	10.34591607	-5.87066407	21.31199655
0.08	13.30705902	-2.10809177	23.87324455
0.09	16.00010005	1.29471302	26.22170131
0.10	18.47904874	4.40877640	28.40168360
0.15	28.74255862	17.06482138	37.66440218
0.20	36.89967092	26.75283908	45.39672292
0.25	43.89774695	34.70900120	52.38566004
0.30	50.18223551	41.52450416	58.99131811
0.35	56.00575073	47.55052638	65.40200172
0.40	61.53169720	53.02635636	71.72738939
0.45	66.87811435	58.12828849	78.04327192
0.50	72.13976608	62.99314087	84.41520905
0.55	77.40141782	67.73337183	90.91176760
0.60	82.74783497	72.44917650	97.61377758
0.65	88.27378144	77.23994287	104.62422887
0.70	94.09729666	82.21757000	112.08330758
0.75	100.38178522	87.52619127	120.19584733
0.80	107.37986125	93.37891401	129.28822382
0.85	115.53697354	100.14243723	139.94503905
0.90	125.80048343	108.58725921	153.41898063
0.91	128.27943211	110.61845366	156.68183185
0.92	130.97247315	112.82193154	160.22961552
0.93	133.93361609	115.24131367	164.13405368
0.94	137.24074886	117.93948152	168.49860238
0.95	141.01255117	121.01221397	173.48093530
0.96	145.44393343	124.61675390	179.34006045
0.97	150.89175461	129.04088557	186.55030198
0.98	158.13368373	134.91147476	196.14558498
0.99	169.54786036	144.14437391	211.28881461

Table 12

DATA ANALYSIS CBD-COMPOSITE MARCH 31,1982

PROBIT ANALYSIS ON DOSE

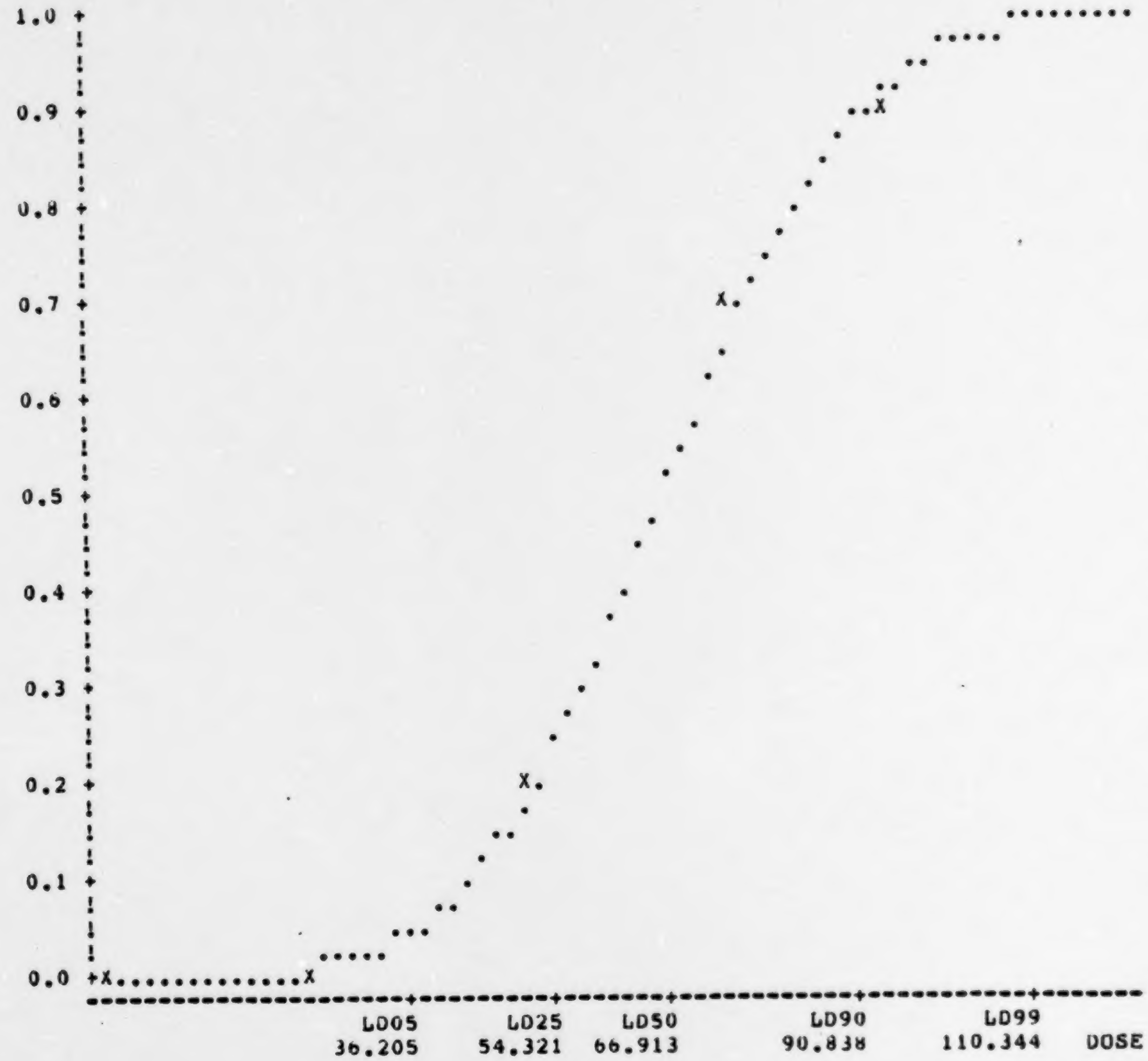

Table 13

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DATA ANALYSIS CBD-COMPOSITE MARCH 31,1982


                     PROBIT ANALYSIS ON DOSE

PROBABILITY             DOSE           95 PERCENT FIDUCIAL LIMITS
                                           LOWER            UPPER

   0.01              23.48267577      -22.34973445      40.25017504
   0.02              28.57182141      -12.48558200      43.89304192
   0.03              31.80072116       -6.25801290      46.23524353
   0.04              34.22969666       -1.59321105      48.01714637
   0.05              36.20548085        2.18618336      49.48164890
   0.06              37.88718352        5.39072059      50.74049159
   0.07              39.36170778        8.18988146      51.85484175
   0.08              40.68196838       10.68677967      52.86202590
   0.09              41.88269258       12.94903043      53.78659786
   0.10              42.98796117       15.02347618      54.64562763
   0.15              47.56406843       23.51353859      58.30093767
   0.20              51.20101342       30.11232749      61.35490579
   0.25              54.32118838       35.62735252      64.12108677
   0.30              57.12320193       40.42790092      66.75731732
   0.35              59.71968507       44.71327153      69.36323070
   0.40              62.18349365       48.60290067      72.01275617
   0.45              64.56725697       52.17495865      74.76740595
   0.50              66.91322663       55.48624693      77.68251788
   0.55              69.25919628       58.58409353      80.81107147
   0.60              71.64295960       61.51416153      84.20771123
   0.65              74.10676819       64.32592301      87.93510437
   0.70              76.70325132       67.07733720      92.07497417
   0.75              79.50526487       69.84117901      96.74791131
   0.80              82.62543983       72.71787739     102.15241893
   0.85              86.26238482       75.86745271     108.65560063
   0.90              90.83849209       79.60680711     117.06161869
   0.91              91.94376068       80.48167475     119.12022657
   0.92              93.14448487       81.42189083     121.36683320
   0.93              94.46474548       82.44460734     123.84819905
   0.94              95.93926973       83.57448658     126.63183084
   0.95              97.62097240       84.84900773     129.82068961
   0.96              99.59675659       86.32957093     133.58402335
   0.97             102.02573210       88.12831329     138.23198568
   0.98             105.25463184       90.48893295     144.44113674
   0.99             110.34377748       94.15400524     154.28308377
```

Table 14

DATA ANALYSIS CBD-FIRST FLUSH MARCH 31,1982

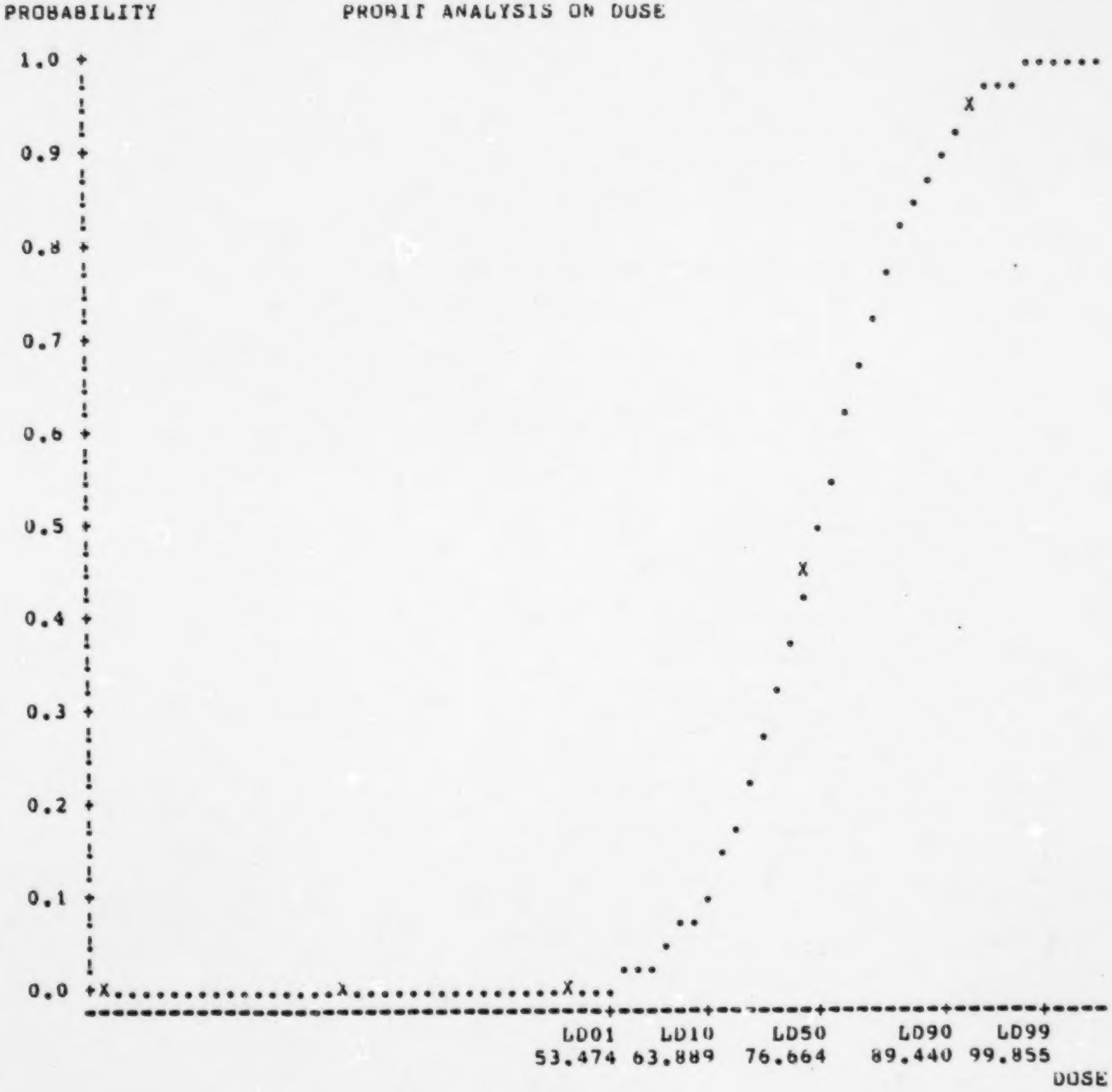

Table 15

DATA ANALYSIS CBD-FIRST FLUSH MARCH 31,1982

PROBIT ANALYSIS ON DOSE

PROBABILITY	DOSE	95 PERCENT FIDUCIAL LIMITS	
		LOWER	UPPER
0.01	53.47373285	28.75727266	62.58030964
0.02	56.19120183	33.95133212	64.50753980
0.03	57.91534877	37.23463385	65.74246802
0.04	59.21235736	39.69673497	66.67925528
0.05	60.26737378	41.69360520	67.44711856
0.06	61.16535847	43.38847961	68.10546660
0.07	61.95271536	44.87045912	68.68680282
0.08	62.65769956	46.19376352	69.21095156
0.09	63.29885447	47.39395349	69.69094631
0.10	63.88903863	48.49567008	70.13584251
0.15	66.33255870	53.01917786	72.01572490
0.20	68.27459100	56.55708074	73.56703354
0.25	69.94068179	59.53556630	74.95463830
0.30	71.43688281	62.15019116	76.26089749
0.35	72.82333603	64.50663375	77.53773831
0.40	74.13894456	66.66764675	78.82435596
0.45	75.41181104	68.67284100	80.15478427
0.50	76.66449669	70.54877051	81.56159228
0.55	77.91718235	72.31525747	83.07784283
0.60	79.19004883	73.99025140	84.73847145
0.65	80.50565736	75.59402558	86.58232793
0.70	81.89211058	77.15297931	88.65665760
0.75	83.38831160	78.70372810	91.02679286
0.80	85.05440239	80.29986077	93.79675052
0.85	86.99643469	82.02837470	97.15744811
0.90	89.43995476	84.06099817	101.52821480
0.91	90.03013891	84.53431609	102.60150968
0.92	90.67129383	85.04226391	103.77374657
0.93	91.37627803	85.59404379	105.06941984
0.94	92.16363492	86.20288019	106.52389917
0.95	93.06161961	86.88886268	108.19113912
0.96	94.11663603	87.68489488	110.15984043
0.97	95.41364462	88.65106180	112.59256189
0.98	97.13779156	89.91793689	115.84391676
0.99	99.85526054	91.88341628	120.99972698

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Appendix I. Taxa List and Number Collected/Station, June, 1980 to May, 1982, Winston-Salem Urban Streams

	Tar Br.	Burk Br.	Salem Cr.-1	Salem Cr.-2	4-Mile Cr.
INTOLERANT GROUPS					
EPHEMEROPTERA					
Stenonema modestum	1	1	153		
S. smithae			10		
Stenacron interpunctatum			34		
Centroptilum sp.	2		2		
Baetis flavistriga	14	1396	1	20	
B. intercalaris		24			
B. brunneicolor		1			
B. propinquus		41	6		
Pseudocloeon	1		1		
Ephemerella catawba		3			
Hexagenis sp.			1		
Leptophlebia sp.			7		
PLECOPTERA					
Allocapnia sp.			5		
TRICHOPTERA					
Cheumatopsyche sp.		25	218		
Hydropsyche betteni	1	33	1		
Taxa Richness (Subtotal):	5	8	12	1	31
FACULTATIVE GROUPS					
COLEOPTERA					
Hydroporus sp.	1		6		
Thermoneutes sp.			1		
Dineutes sp.			4		
Stenelmis sp.		1			
Macronychus glabratus		1			
ODONATA					
Progomphus obscurus			43		
Calopteryx sp.			1		
Aeschna sp.		1			
Boyeria vinosa				1	
MEGALOPTERA					
Sialis sp.			2		
CRUSTACEA					
Cambarus sp.	3	75	9	1	
Lirceus/Asellus	3	17	7		
Crangonyx sp.		18			

	Tar Br.	Burk Br.	Salem Cr.-1	Salem Cr.-2	4-Mile Cr.
MOLLUSCA					
Ferrissia sp.		7	1		
Gyraulus sp.		1		1	
Phsya sp.					62
Pisidium sp.		9	31		
OTHER					
Prostoma graecens			1		
Dugesia tigrina		1			
Sigara sp.			1		
Taxa Richness (subtotal)	3	10	12	4	18
TOLERANT GROUPS					
DIPTERA: CHIRONOMIDAE*					
1. Toxic Assemblage					
Cricotopus/Orthodadius sp. 1	1009	20	46	9840	
C/O sp. 5	1855	4	70	11,257	
C/O sp. 6	34	37	6	766	
C/O sp. 3	4	1		288	
Conchapelopis group	483	597	106	1,928	
Natarsia sp.	11	6	1	3	
Psectrotanypus dyari	15			2	
Polypedilum illinoense	59	139	750	1,671	
2. Organic/Enrichment					
Chironomus sp.	14	6	36	7	
Dicrotendipes sp.		1		2	
Rheotanytarsus sp.		4	44		
3. Sediment					
Cricotopus/Orthocladius sp. 7		4			
C/O sp. 10		31		4	
C/O sp. 12		7			
C/O sp. 54		87		1	
Cardiocladius sp.		5		1	
Diplocladius Cultriger		56			
Paraphaenocladius sp. 1	12	129	11		
Rheocricotopus sp. 1		4	4	1	
Rheosmittia sp.		41			
Thienemaniella sp.		2	1		
Diamesa sp.		8			
Polypedilum halterale	1	5	64		
P. scalaenum		2	150		

*5 most abundant (at each station) underlined.

	Tar Br.	Burk Br.	Salem Cr.-1	Salem Cr.-2	4-Mile Cr.
Stictochironomus sp.		14			
4. Other or Unclassified					
Cricotopus/Orthocladius sp. 8		2			
C/O sp. 9	17			74	
C/O sp. 14		2			
C/O sp. 41	8				
C/O sp. 47		4			
C/O sp. 48			1		
Eukiefferiella sp. 1		48			
E sp. 3		2			
E sp. 11	2	60		32	
Bryophaenocladius sp.		1			
Corynoneura sp.		49			
Paracricotopus sp.	1	29			
Brillia sp.		7		16	
Limnophyes sp.	1	1			
Nanocladius sp.				4	
Parakiefferiella sp. 1			3		
Paraphaenocladius sp. 2		1			
Odontomesa fulva		5	2		
Tanytarsus sp.		26	76		
Paratanytarsus sp.		1			
Tribelos sp.		1	39		
Cryptochironomus fulvus		9	6		
Saetheria tylus		1	102		
Microtendipes sp.		1			
Phaenopsectra flavipes		3			
Polypedilum aviceps		33			
P laetum		1	6		
P fallax		2	-		
Stenochironomus		-	2		
Ablabesmyia ornata	4		10		
A parajanta			3		
Procladius sublettei	4		1		
Zavrelimyia		3	2	4	
Taxa Richness (Subtotal)	18	48	26	19	26

	Tar Br.	Burk Br.	Salem Cr.-1	Salem Cr.-2	4-Mile Cr.
DIPTERA: MISCELLANEOUS					
Palpomyia (complex)	6		8	16	
Culicordes sp.	42				
Atrichopogon sp.				17	
Tipula sp.		5	19		
Hexatoma sp.		1	112		
Antocha sp.	3	1			
Pseudolimnophila sp.		1	16		
Limonia sp.	6			3	
Polymeda/Ormosia		1			
Chrysops sp.				4	
Bittacomorpha sp.		5	1		
Simulium spp.		35	34		
Psychoda sp.	3				
Culex restuans	5				
Muscidae	1			1	
Empididae	1	66	136	1	
Polichopodidae	3	1			
OLIGOCHAETA					
1. Organic indicators					
Limnodrilus spp (immature)	482	82	284	6195	
L. hoffmeisteri	13	34		1089	
L. udekamianus	-	2	36	108	
Tubifex tubifex	26	3	41	1237	
Ilyodrilus templetoni	1	5	22	48	
Nais sp.	343	15	181	6674	
Pristina sp.	3708	60	5	36	
2. Other					
Aulodrilus limnobius			4		
L. claparedeanus		80		14	
Lumbriculidae	82	401	81	208	
Enchytraeidae			4	84	
Opisthopora	2	1		16	
Taxa Richness (subtotal)	17	19	16	17	12
Total Taxa Richness:	43	85	66	41	92

APPENDIX II

Pollutant Loading
(lbs./acre/year)

Parameter	Residential	Central Business District
TS	836.49	3927.88
TSS	624.76	2632.45
BOD	60.49	160.70
COD	156.45	981.34
TKN	2.61	13.00
NH_3	.31	4.41
NO_2NO_3	1.25	9.39
TP	1.04	3.68
TOP	.21	.96
CU	.06	.70
PB	.42	3.59
ZN	.31	4.78
HG	.001	.31

APPENDIX 3

ATMOSPHERIC DEPOSITION STUDY
WINSTON-SALEM/FORSYTH COUNTY
URBAN RUNOFF PROJECT

June 1982

Forsyth County
Environmental Affairs
Department

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ABSTRACT

Analysis of atmospheric deposition data collected over a two year period in Winston-Salem, North Carolina, led to the conclusion that local wetfall pollutant deposition is generally area wide in distribution, i.e., for any given month's composited wetfall, the amount of pollutant loading in each of the two investigated watersheds (Central Business District and Ardmore Residential Area) tends to be similar. Monthly dryfall deposition, however, appears to be influenced by local, more immediate sources and may vary significantly within short distances.

Pollutant loads were analyzed for both nutrient and metallic pollutant constituants, including ammonia, total kjeldahl nitrogen, nitrates/nitrites, total phosphorus, copper, lead, zinc, mercury, cadmium, cobalt, chromium, manganese and nickel. While all of the four analyzed nutrients were detectable during the two years of the study, only four of the analyzed metals were ever present in amounts above the minimum detectable limit: copper, zinc, lead and mercury. Nutrient pollutants were found most often in association with the wetfall samples, while metals were observed most frequently in the dryfall samples.

The acidity of monitored wetfall samples was analyzed and reported in pH units. The mean pH value calculated for the study, from both of the watersheds, was approximately 3.8. This value is below the 5.6 pH level indicative of pure rainfall, as would be expected from reports of other studies of east coast acid precipitation.

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PREFACE

Authorization

In September, 1979, the Forsyth County Environmental Affairs Department entered into a contract with the North Carolina Department of Natural Resources and Community Development, Division of Environmental Management (NRCD-DEM) to participate in a study of urban stormwater quality management in Winston-Salem, North Carolina. Responsibility for an atmospheric deposition research task was taken by the Environmental Affairs Department. This report fulfills an obligation of the intergovernmental agreement to complete the atmospheric deposition task.

Purpose

The Winston-Salem/Forsyth County Urban Runoff Project was divided into several dependent tasks, one of which was the atmospheric deposition study. The purpose of the study was to determine the potential pollutant contribution of atmospheric wetfall and dryfall to area streams. This report will detail the findings of the study, attempt to explain and interpret the results of several different analyses, and suggest areas of interest for future investigation.

The report is not intended to stand alone as a summary of urban runoff problems. The results outlined herein provide information to be used in the completion and interpretation of other project reports.

Scope

Data from three monitoring stations were used in the preparation of this report, as listed in Table 1. Two were situated in the central business district (CBD) of Winston-Salem; one of the two, located at the Cherry Street Parking Deck, was sited to represent watershed-wide patterns, (Cherry Deck), while the other, located at the intersection of Second and Trade Streets, was sited to include a possible streetside bias (Second Street). The third monitor was established in the Ardmore residential area (RES), and was used to represent watershed-wide patterns. Intercomparisons of the two watersheds (CBD and RES) were conducted, as well as intracomparisons within the CBD. Figures 1, 2 and 3 show the location of the two watersheds. A detailed description of the watersheds and their monitoring sites may be found in a companion report prepared by the NRCD-DEM.

Each monitoring station contained equipment to collect wetfall and dryfall, and to measure wind speed, wind direction, and wetfall amounts. In addition, a high-volume air sampler was operated at the Cherry Deck site to measure concentrations of atmospheric total suspended particulate matter.

Analyses contained in this report included data from the time period beginning in August, 1980, and ending April, 1982. It should be noted that monitoring in the residential watershed did not begin until March, 1981, at which time an ammendment to the original project work plan included that area in the atmospheric deposition study.

Background

The 1978 Ninth Annual Report on Environmental Quality, issued by the Council on Environmental Quality (CEQ), lists atmospheric deposition in its water quality section as an "issue(s) to watch." The report states the following regarding atmospheric deposition and its inherent association with water quality management:

> Atmospheric deposition needs to be considered carefully when water quality goals are set and control of pollution from point sources and non-point sources is planned. To effect stream quality levels that meet established water quality standards and criteria, then, may require elimination of virtually all controllable point sources of pollution and influences on water quality from non-point sources and/or reduction of atmospheric contributions through control of air pollution.
>
> Management of both air and water quality needs legislation, standards, and regulations that apply to both air and water. We can expect to see such legislation and enforcement agencies in the future. Integrated air and water data and models of the movement of materials through the atmosphere and on the earth are a prerequisite.
>
> Data and monitoring provide the bases for identifying needs and setting priorities for pollution control, for managing water resources, and for evaluating success of programs.

The term atmospheric deposition, as used in this report, is intended to include both wetfall and dryfall of atmospheric contaminants. Wetfall involves all types of precipitation and those contaminants scavenged during their deposition, while dryfall is defined as the gravitational sedimentation and impaction of atmospheric contaminants.

Numerous studies throughout the past five to ten years have strongly implicated atmospheric deposition as a major contributor to urban related water pollution. Heaney and Sullivan, as early as 1971, estimated that up to seventy-five percent of the pollutants found on street surfaces could be attributed to atmospheric deposition. Winchester and Duce, in their 1975 review of air-water exchange of particulates, stated that direct atmospheric input of pollutants into both fresh and salt bodies of water, may, in certain cases, actually rival direct water discharge. Patterson (reported in Duce et al., 1974) for example, found that approximately forty-five percent of the lead entering his study area of the Southern California Bight could be attributed to atmospheric deposition, while the remaining fifty-five percent originated from river input, storm runoff and discharged waste water.

Urban involvement in this type of atmospheric pollution was further documented through studies by the Urban Stormwater Pollution Research Group in Great Britain which demonstrated a positive correlation in atmospheric fallout between heavy metal concentrations and population density. These data indicated heavy metals accounted for between thirty and seventy percent of the total outfall quality, with nutrients, such as phosphorus and nitrogen, contributing a smaller yet significant percentage (Ellis, 1978).

An additional element in the study of urban related atmospheric deposition, and one that is currently receiving much public attention, is the phenomenon of "acid rain." Acid deposition is generally defined as either rain or snow whose pH is less than the "normal" value of 5.6. This slightly acidic condition of rainwater is considered "normal" due to the naturally occurring carbonic acid component, the product of a reaction between rain water and the carbon dioxide in the atmosphere. Additional acidity is formed in rain or snow from a reaction with the gases sulfur oxide and nitrogen oxide which currently exist as atmospheric pollutants in most urban areas.

Atmospheric data collected as part of the Forsyth Urban Runoff Study were intended to identify those deposited atmospheric pollutants which were contributing to the degeneration of Forsyth County streams as a result of stormwater runoff. Both wet and dry deposition were collected by the Environmental Affairs Department's Analysis and Monitoring Division, in each of the two watersheds under study, beginning in the summer of 1980. These samples have been analyzed both in-house (pH and conductivity) and by the North Carolina Department of Natural Resources and Community Development, Division of Environmental Management laboratory (metals and nutrients), and the results are presented herein. Additional augmenting data pertaining to wind speed and direction, rainfall amounts, total suspended particulates and automotive traffic were also collected and analyzed.

TABLE 1

MONITORING SITES

NAME	NUMBER	LOCATION
Cherry Deck	NC10110	On the upper level of the four story parking garage, bounded by Trade Street, Second Street, Cherry Street, and Third Street.
Second Street	NC10210	At ground level on the southeast corner of the intersection of Second and Trade Streets.
Residential	NC10310	On the roof of the one story supermarket, immediately south of the intersection of Hawthorne Road and Knollwood Street.

Figure 1

LOCATION OF WATERSHEDS IN STUDY

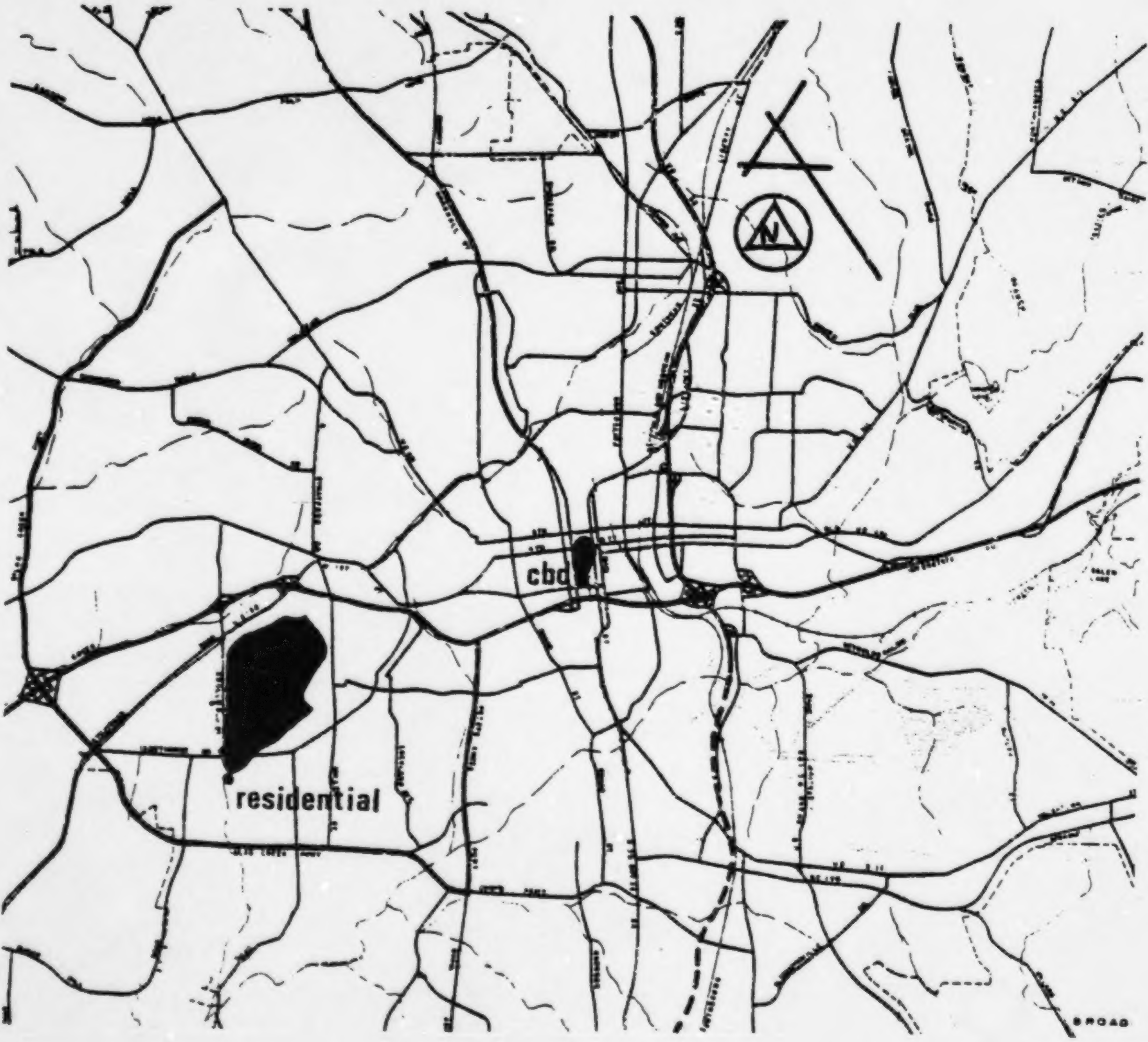

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Figure 2

RESIDENTIAL WATERSHED

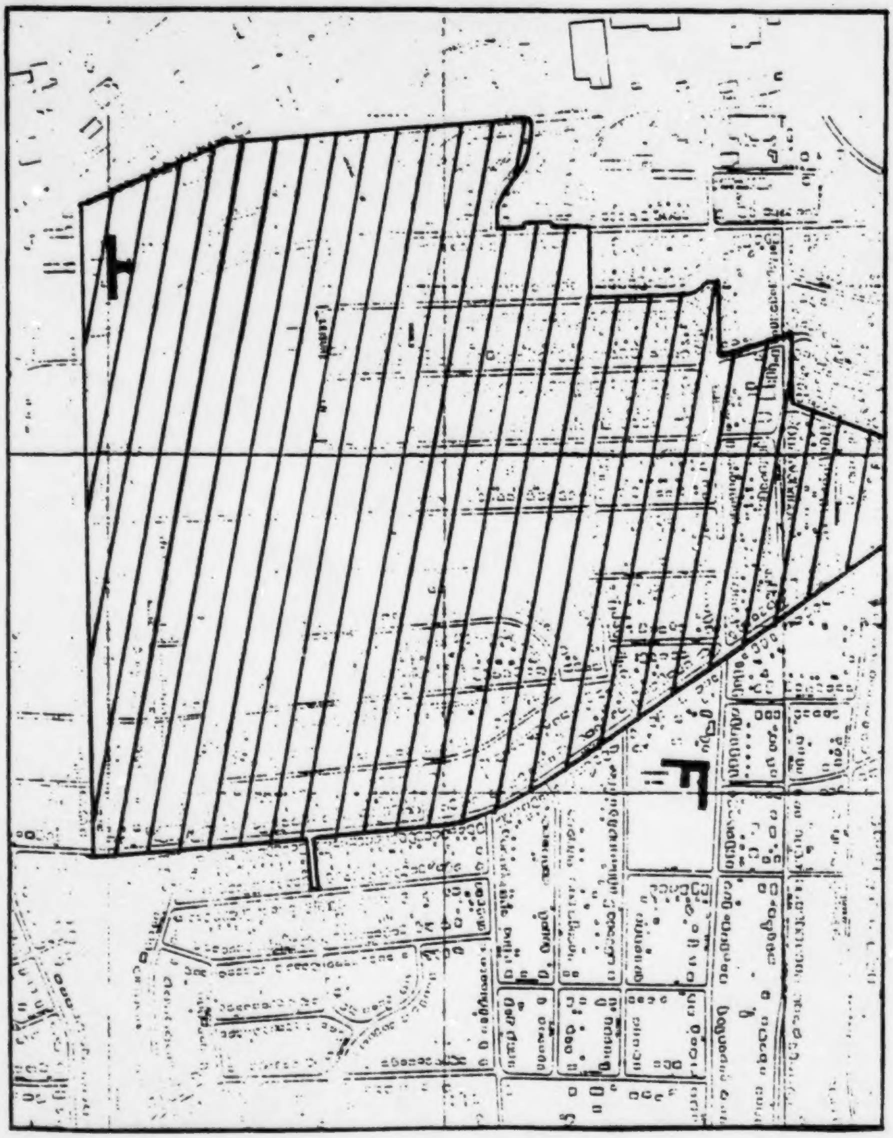

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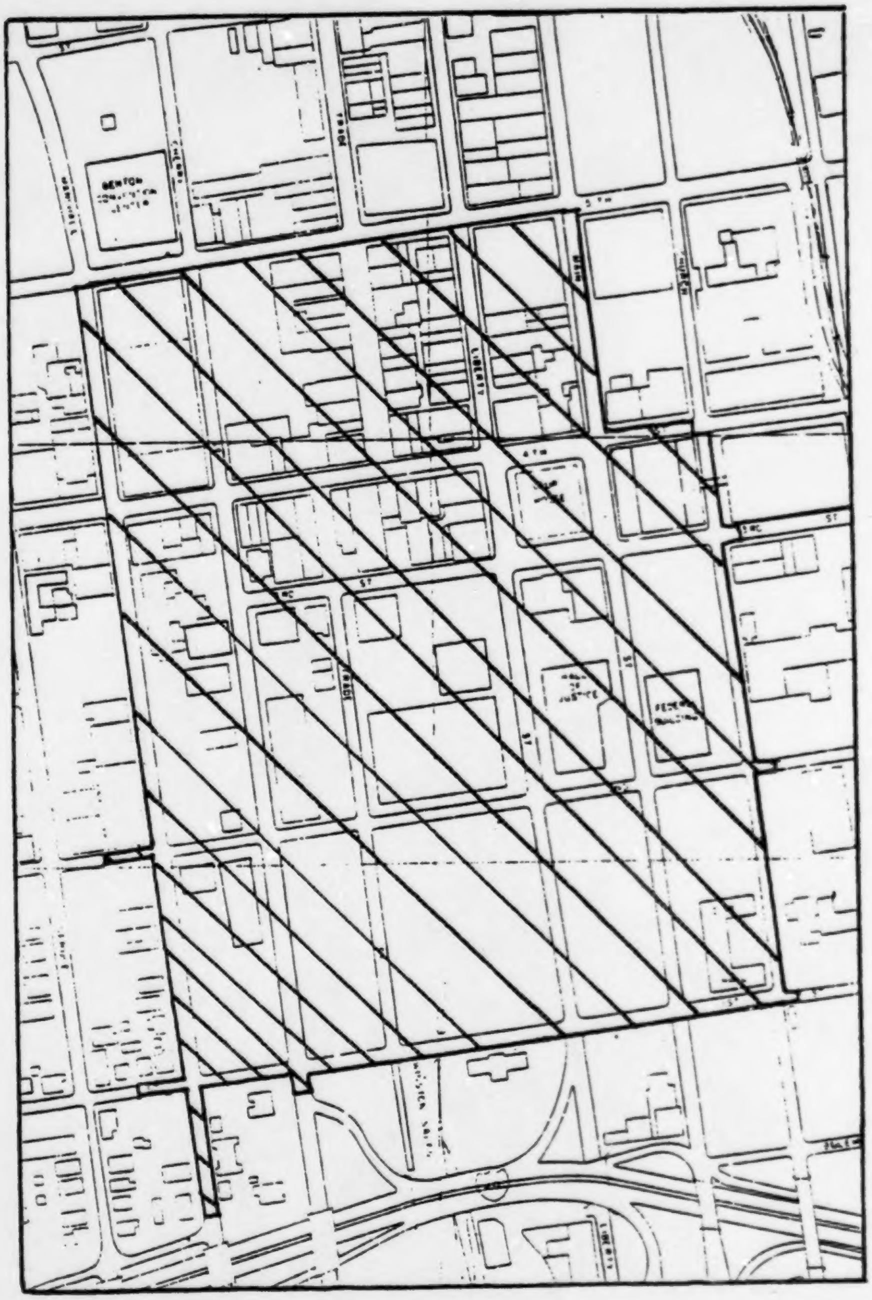
Figure 3

CENTRAL BUSINESS DISTRICT
WATERSHED



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METHODS

Wetfall Sampling

Wetfall was collected for analysis using an Aerochemetrics Model 301 sampler at each of the three monitoring sites. Sample containers were retrieved and replaced with clean containers after every rain event. An event was recorded when enough rain had fallen to initiate runoff from street surfaces within the watershed. Events were separated by a time span of at least six dry hours, i.e., six hours without any detected wetfall.

Samples were analyzed for pH and conductivity in the Environmental Affairs Department (EAD) laboratory, bottled with appropriate preservatives, and forwarded to the NRCD-DEM laboratory for nutrient and metal analyses.

Dryfall Sampling

Aerochemetrics Model 301 samplers were also used for dryfall sample collection at all three monitoring stations. Sample containers were retrieved and replaced with clean containers at 9 o'clock a.m. on the first Tuesday of every month. Due to the automated design of the samplers, dryfall and wetfall sampling periods were entirely discrete, i.e., their periods of collection did not overlap.

In the EAD laboratory, dryfall samples were removed from their collection containers by sequential rinsing with small volumes of ultra-pure water until a total of one liter of water dilution had been added. These dilute samples were then bottled with appropriate preservatives and forwarded to the NRCD-DEM laboratory for nutrient and metal analyses.

Meteorological Monitoring

Rainfall amounts, as well as wind speed and direction, were monitored at each of the three monitoring sites, using Belfort Model 5-780 rain gauges and Weathertronics Models 2020 and 2030 wind instruments. The Cherry Deck instruments were unobstructed and monitored at a height of approximately seventy (70) feet, while the Second Street instruments were located at ground level (street side) and indicative of only that confined micro-environment.

The Residential meteorological station was sited on the roof of a single story supermarket and was considered to be representative of the residential watershed. Its lower and more biased location did not, however, lend itself to collecting data representing a more regional area.

Total Suspended Particulate Sampling

Total suspended particulate (TSP) concentrations were determined for 24-hour air samples collected at the Cherry Deck site using the federal reference method (40 CFR 50, Appendix A). The operation, calibration, quality assurance and maintenance of this single air particulates monitor were conducted as an intergral part of the ongoing EAD air monitoring network.

Data Analysis

Wetfall and dryfall pollutant loadings were analyzed to determine inter- and intra-watershed relationships. Levels were reported in units of pounds per acre. This unit was chosen for two reasons: total pollutant loading could be determined for any given surface area within a watershed, and a possible initial washout bias could be eliminated from the wetfall data calculations. Investigators have shown that a large percentage of the pollutant load in wetfall samples is collected during the first few minutes of a shower or storm. Additional precipitation simply dilutes the sample, resulting in a lower concentration of the componant pollutants (Randall, et al, 1978; Slanina, et al, 1979).

Certain pollutants were occasionally undetected during laboratory analysis of deposition samples. While their presence was not totally ruled out, these samples were not included in data sets used for analysis. This was done to negate the effect on monthly rainfall compilations introduced by repeated additions of amounts greater than zero, but less than the detectable limit. Likewise, zero was not used in these compilations because of the potential for bias in the opposite direction. As a result, some of the statistical comparisons discussed may be conservative in their conclusions, indicating no apparent differences when they may have actually existed.

Paired sample t-testing was employed during data analysis to test the null hypothesis Ho: $\mu_1-\mu_2= 0$, where $\mu_1-\mu_2$ is defined as the mean population difference between two paired data sets (Ostle, 1963; Zar, 1974). Each value from one of the sets may be labelled Xi and is paired with a value from the other set, Yi. The total number of paired samples is n, and i - 1 to n. The following formulae are used to determine the test statistic, t, which has n-1 degrees of freedom:

$$Di = Xi - Yi$$

$$\bar{D} = \frac{1}{n} \Sigma\, Di$$

$$S_D = \sqrt{\frac{\Sigma Di^2 - \frac{1}{n} (\Sigma Di)^2}{n - 1}}$$

$$S_{\bar{D}} = \frac{S_D}{\sqrt{n}}$$

and, $$t = \frac{\bar{D}}{S_{\bar{D}}}$$

Linear correleation analyses were used to investigate possible linear relationships between two variables, when neither was assumed to be functionally dependant upon the other. Using the variable notation outlined above (Xi, Yi), a correlation coefficient was calculated as:

$$r = \frac{\Sigma\, XY}{\sqrt{\Sigma X^2\ \Sigma Y^2}}$$

A coefficient of determination was calculated by squaring the correlation coefficient, r. It may be defined as "the amount of variability in one of the variables (either Y or X) accounted for by correlating that variable with the second variable,"(Zar, 1974).

ATMOSPHERIC DEPOSITION ANALYSIS - NUTRIENTS

Introduction

Deposition samples were analyzed for constituent nutrient concentrations including ammonia, total kjeldahl nitrogen, nitrate/nitrite as nitrogen, and total phosphorus. Dryfall samples were collected and analyzed each month and a monthly pounds per acre deposition value was computed for each pollutant. Wetfall analyses were, however, undertaken on a per event basis and were, therefore, composited monthly for the purpose of intercomparison. A summary of the observed pollutant loading in each of the two sample types from all three sampling stations is presented in Table 2.

Nitrogen - Ammonia (NH_3)

General:

Ammonia, one of the chemically interconvertible components of the nitrogen cycle, is naturally present in both surface and ground water. It is produced largel by the deamination of nitrogenous organic matter and the hydrolysis of urea. It may also result from the reduction of nitrate under anaerobic conditions. Other sources include the discharge of industrial wastes from chemical and gas plants, from ice plants, and where it is used in scouring and cleaning operations. Additionally, because it changes rapidly to nitrites and nitrates, ammonia is a fertilizer for most crops; ammonium salts constituting a major source of nitrogen fertilizer (Shelley, 1979). In urban air ammonium sulfate aerosols are often formed from oxidation of ammonia and SO_2 (Bach, 1975).

Data analysis:

Paired t-comparisons of monthly NH_3 data from the Cherry Deck and Second Street CBD stations showed no significant differences between their wetfall or their dryfall depositions. Interwatershed comparisons (CBD to RES), likewise, showed no significant differences in their NH_3 distributions. However, when each of the three stations' monthly dryfall NH_3 values were compared with their own monthly wetfall NH_3 values, a highly significant difference was calculated (Deck, $t_{.001[18]} = 4.13$; Street, $t_{.001[18]} = 3.99$; RES, $t_{.05[8]} = 2.73$). This indication of a significantly greater wetfall contribution of ammonia would be expected, due to the highly water soluble, gaseous nature of this pollutant.

Linear correlation of monthly wetfall NH_3 data from the Cherry Deck and Second Street stations was significant at the .001 level, $r^2_{[19]} = .8850$ (Figure 4), while correlation between the two watersheds (using Cherry Deck and RES) was slightly less significant at the .01 level, $r^2_{[12]} = .4859$ (Figure 5). This watershed to watershed correlation between monthly wetfall NH_3 depositions tends to indicate a more area wide distribution of this pollutant, as was also seen in the other nitrogenous pollutants investigated (Total Kjeldahl Nitrogen and NO_3/NO_2).

Seasonal wetfall and dryfall distributions of NH_3 monthly means at all three of the monitoring stations supported the predominantly wetfall related deposition of this pollutant (Figure 6 and Figure 7). As might also be expected, the summer wetfall ammonia levels were consistantly higher at all three of the monitoring sites. Of the three, the RES station, with its proximity to a greater mass of decaying vegetation was seen to be the highest. The lowest levels of NH_3 deposition, however, were seen in the dryfall during the summer months. These low levels were also consistant at all three stations; this distribution, however, is not understood.

Nitrogen - Total Kjeldahl (TKN)

General:

Kjeldahl Nitrogen is defined as the sum of free-ammonia and organic nitrogen compounds which are converted to ammonium sulfate $(NH_4)_2SO_4$ under conditions of digestion. Organic nitrogen includes natural materials such as proteins and peptides, nucleic acids and urea, and numerous synthetic organic substances (Shelley, 1979).

Data analysis:

No significant differences in TKN deposition were determined from either the individual station wetfall to dryfall paired comparisons, the intra-CBD paired comparisons, or the watershed to watershed paired intercomparisons.

As with NH_3 and NO_3/NO_2, wetfall distribution of TKN appeared to be an area wide occurrence. This was illustrated by the linear correlation of the Cherry Deck monthly wetfall TKN values with the Second Street monthly wetfall TKN values, $r^2_{.001[22]} = .8220$ (Figure 8), along with the correlation of the Cherry Deck monthly TKN values with the RES monthly TKN values, $r^2_{.002[12]} = .5764$ (Figure 9). The correlation of the Cherry Deck monthly dryfall TKN values with the Second Street monthly TKN values was likewise linear, $r^2_{.05[18]} = .2562$ (Figure 10), while the Cherry Deck dryfall TKN values correlated with the RES dryfall TKN values indicated no significant linearity, $r^2_{[9]} = .0677$.

Seasonal distributions of both the wetfall and the dryfall TKN monthly means (Figures 11 and 12) illustrated the relative continuity of TKN deposition throughout the year, with the possible exception of the summer wetfall values from the residential site. This somewhat elevated TKN value probably resulted from the NH_3 component whose levels at this station are similarly aligned during these months. As with the summer dryfall NH_3 at the residential site, the TKN values during this period were also reduced.

Linear correlations of other monitored nitrogenous pollutants with TKN values strongly illustrated their native interrelationships. For example, monthly wetfall TKN values from the Cherry Deck site correlated with monthly wetfall NH_3 values from the same site at the .001 level of significance, $r^2_{[20]} = .8708$ (Figure 13), while the dryfall TKN values correlated with the dryfall NH_3 values at this site were significant at the .05 level, $r^2_{[18]} = .2144$ (Figure 14). Likewise, TKN wetfall values from the Cherry Deck site, when correlated with the NO_3/NO_2 wetfall values from the same site, were significnat at the .001 level, $r^2_{[20]} = .7839$ (Figure 15), while the dryfall values for these pollutants at the site were significant at the .002 level, $r^2_{[18]} = .4530$ (Figure 16).

Nitrogen, Nitrate/Nitrite (NO_3/NO_2)

General:

Nitrate and nitrite are both chemically interconvertible compounds of the nitrogen cycle. In the atmosphere, nitric oxide (NO) and a comparatively small amount of nitrogen dioxide (NO_2) are formed under high temperature conditions such as those that accompany the burning of fossil fuels. They are emitted to the atmosphere from automobile exhausts, furnace stacks, incinerators, and vents from certain chemical processes. Additionally, lightning discharges can initiate the otherwise slow combination of N_2 and O_2 to form NO. Once formed, the NO_2 may dissolve in rainwater to form nitrates and nitrites.

Data analysis:

No significant difference was established between the street side CBD monitor and the roof top CBD monitor in either the wetfall or the dryfall

NO_3/NO_2 data. Both the Cherry Deck and Second Street dryfall NO_3/NO_2 depositions were, however, significantly higher than the RES deposition (Deck, $t_{.001[7]} = 12.86$; Street, $t_{.001[7]} = 10.85$). When considering the automotive input of nitrogen oxides in the central business district, their prevalence, relative to the less congested residential watershed is understandable. Additionally, results from micro-analysis of selected TSP filters from the Cherry Deck site high-volume air sampler indicate some correlation between nitrate and vehicle exhaust concentrations. The three analyzed filters having the highest nitrate concentrations were also the three having the highest lead concentrations, which suggests that local traffic may be a significant contributor of deposited dryfall nitrates.

Further comparisons of NO_3/NO_2 deposition showed a significantly higher content in the wetfall than in the dryfall depositions at each of the three stations (Cherry Deck, $t_{.02[18]} = 2.84$; Second Street, $t_{.01[17]} = 3.16$; RES, $t_{.02[7]} = 3.37$). Nitrogen oxides are thought to exist as an aerosol, however, as supported here, their gaseous nature is known to predominate.

Linear correlations between the CBD Cherry Deck NO_3/NO_2 wetfall and dryfall values, and the RES NO_3/NO_2 wetfall and dryfall values showed a highly significant linearity in both categories (wetfall, $r^2_{.001[12]} = .8980$, Figure 17; dryfall, $r^2_{.001[7]} = .9190$, Figure 18). Though the central business district is thought, generally, to be the more nitrogen oxide impacted of the two watersheds, these highly significant trend lines indicate an apparent consistency in their ratios of deposition.

Seasonal distributions of dryfall NO_3/NO_2 clearly illustrate this pollutant's year round predominance in the central business district (Figure 19). In the wetfall seasonal distributions (Figure 20), however, this pattern is not generally indicated. The more elevated wetfall levels, as compared with the dryfall levels, do demonstrate the greater incidence of NO_3/NO_2 in the rainfall in both watersheds monitored.

Total Phosphorus (TP)

General:

Phosphorus in its elemental form (yellow phosphorus) does not occur free in nature; however, phosphorus as phosphate is abundant in nature and also appears from the activities of man. Phosphates occur as a result of leaching from minerals and ores in natural processes of degradation. Major uses include fertilizers, detergents and industrial chemicals. Organic phosphates are used extensively in pesticides. Total phosphorus is defined as all of the phosphorus present in the sample, regardless of form, as measured by the persulfate digestion procedure (Shelley, 1979).

Data analysis:

While measurable amounts of total phosphorus were present in approximately 95% of the dryfall samples, this pollutant was detected in only 7% of the wetfall events. No significant differences were established between the two watersheds (CBD to RES) when comparisons of the dry TP deposition amounts were undertaken. The levels of total phosphorus in the dryfall at Second Street in the CBD were, however, marginally higher than the dryfall levels from the nearby elevated Cherry Deck ($t_{.50[17]} = 1.194$). Data from the analyses of suspended particulate filters exposed at the Cherry Deck monitor suggest a traffic related impact of such soil associated elements. Observed mineral particles were generally of a large size; an indication that the dominant mineral emission sources had to be located within a few hundred feet of the sampling site.

Given this information and the monitoring location of the two CBD stations, in the immediate vicinity of the large, unpaved, downtown parking lots, such a soil related impact is highly likely. Furthermore, the positioning of the Second Street monitor directly adjacent to these unpaved lots could possibly explain its somewhat greater dryfall phosphorus loadings, as compared with the elevated Cherry Deck phosphorus loadings collected some distance away.

Seasonal comparisons of dryfall total phosphorus data seem to support a greater CBD over RES distribution, though no statistical significance was derived from their paired t analysis (Figure 21). As was stated above, the incidence of wetfall TP was measured in only 7% of the rain events monitored and as such, the seasonal wetfall graphics are inconclusive (Figure 22).

Table 2

MONTHLY RANGES, MEANS AND STANDARD DEVIATIONS OF OBSERVED LOADING OF NUTRIENT CONSTITUENTS IN WETFALL AND DRYFALL SAMPLES (LBS/ACRE).

Pollutant	Station	Range of Observations		Mean		Std. Dev.		Number of Monthly Samples With Detected Amounts	
		Wetfall	Dryfall	Wetfall	Dryfall	Wetfall	Dryfall	Wetfall	Dryfall
NH_3	Deck	.018-.343	.013-.158	.140	.056	.080	.039	20	20
	Street	.019-.353	.009-.144	.164	.058	.083	.041	21	20
	Res	.068-.410	.013-.102	.172	.045	.120	.034	13	10
TKN	Deck	.021-.358	.058-.476	.178	.156	.090	.112	21	21
	Street	.025-.434	.058-.302	.201	.158	.111	.057	21	20
	Res	.075-.477	.029-.187	.181	.110	.110	.062	13	90
NO_3/NO_2	Deck	.021-.451	.040-.135	.163	.086	.101	.031	21	20
	Street	.030-.460	.048-.634	.176	.114	.110	.132	21	19
	Res	.062-.486	.007-.063	.174	.030	.118	.024	13	8
TP	Deck	.013	.009-.132	.013	.030	-	.029	1	21
	Street	.004-.042	.009-.063	.015	.033	.016	.016	5	19
	Res	.008-.024	.007-.036	.014	.018	.008	.010	3	8

NOTE: Central business district data (Deck and Street) are derived from twenty-one months of sampling, while residential (Res) data represent thirteen months of sampling.

Figure 4

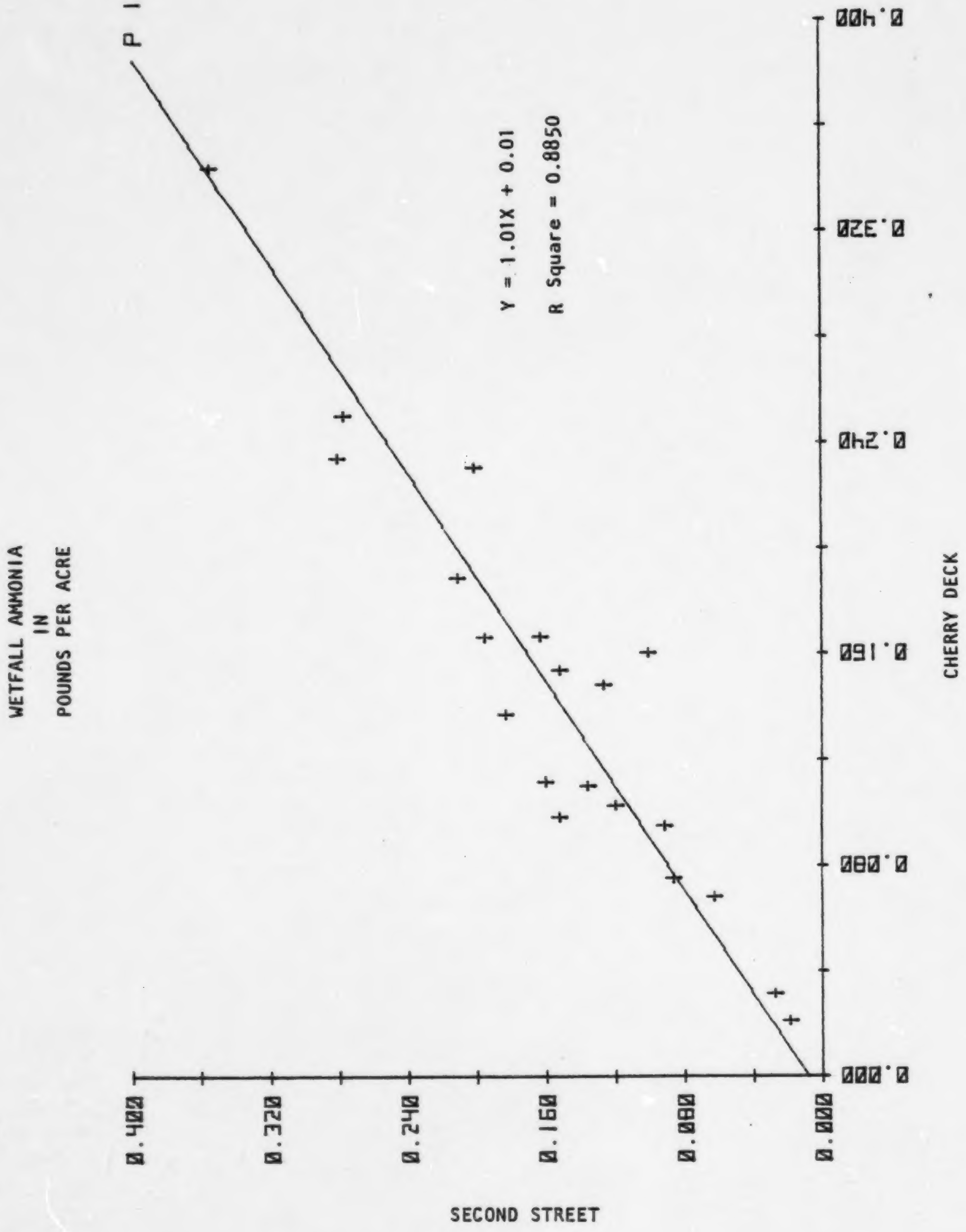

WETFALL AMMONIA
IN
POUNDS PER ACRE
Y = 1.01X + 0.01
R Square = 0.8850
P I
SECOND STREET
0.000
0.080
0.160
0.240
0.320
0.400
CHERRY DECK
0.000
0.080
0.160
0.240
0.320
0.400

Figure 5

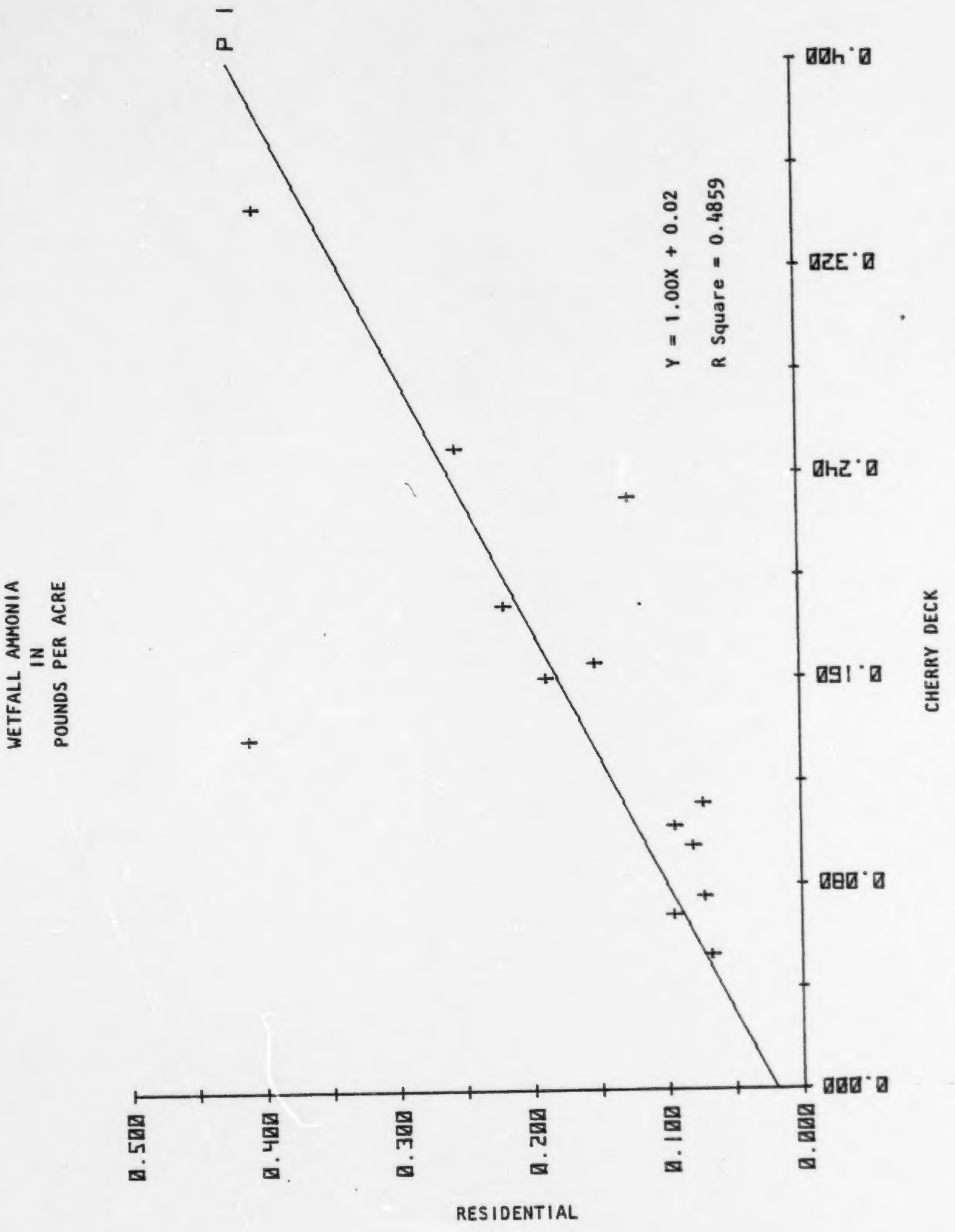
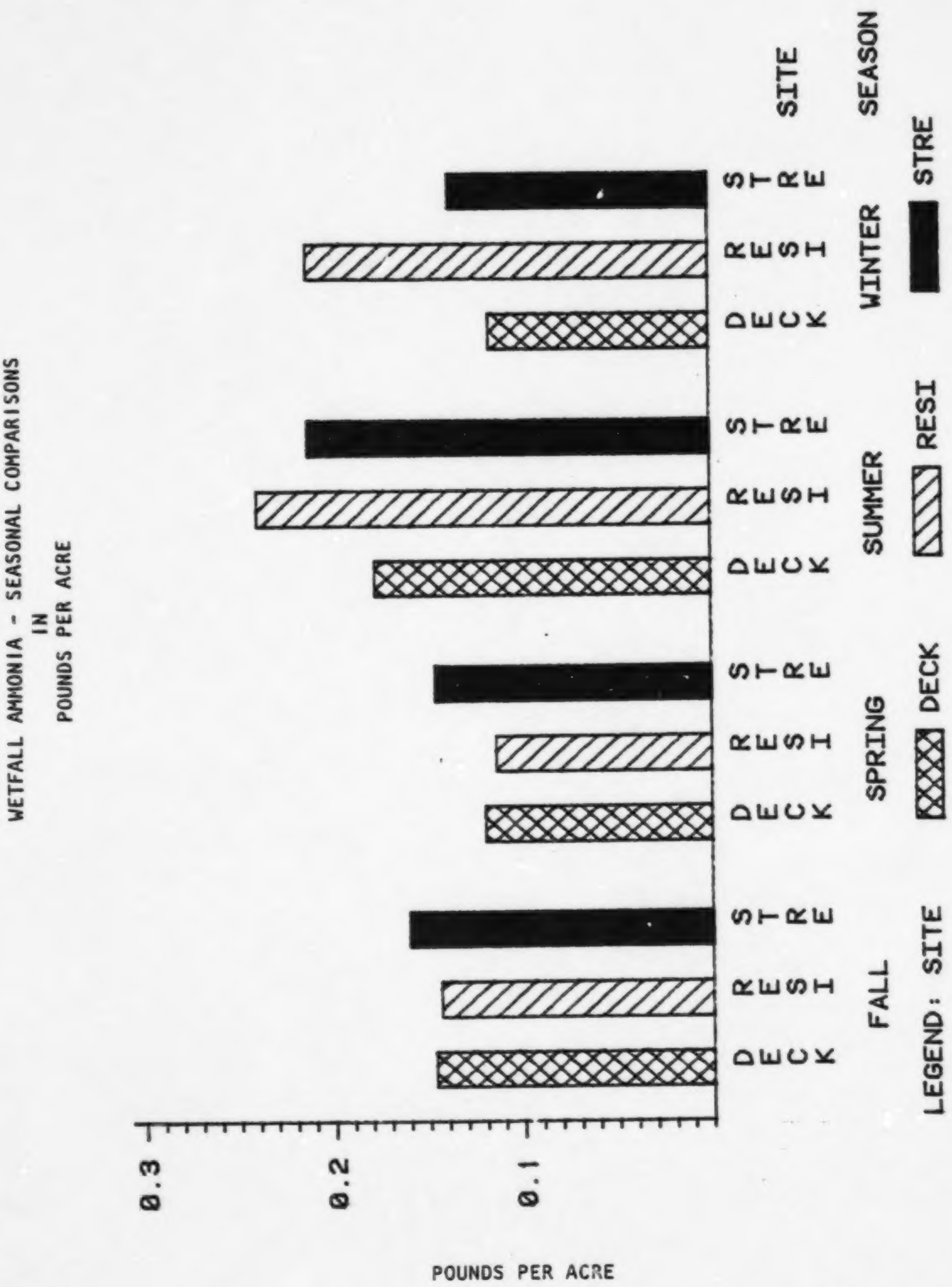

WETFALL AMMONIA
IN
POUNDS PER ACRE
P I
Y = 1.00X + 0.02
R Square = 0.4859
0.000
0.080
0.160
0.240
0.320
0.400
CHERRY DECK
0.000
0.100
0.200
0.300
0.400
0.500
RESIDENTIAL

Figure 6



WETFALL AMMONIA - SEASONAL COMPARISONS IN POUNDS PER ACRE

Figure 7

DRYFALL AMMONIA - SEASONAL COMPARISONS
IN
POUNDS PER ACRE

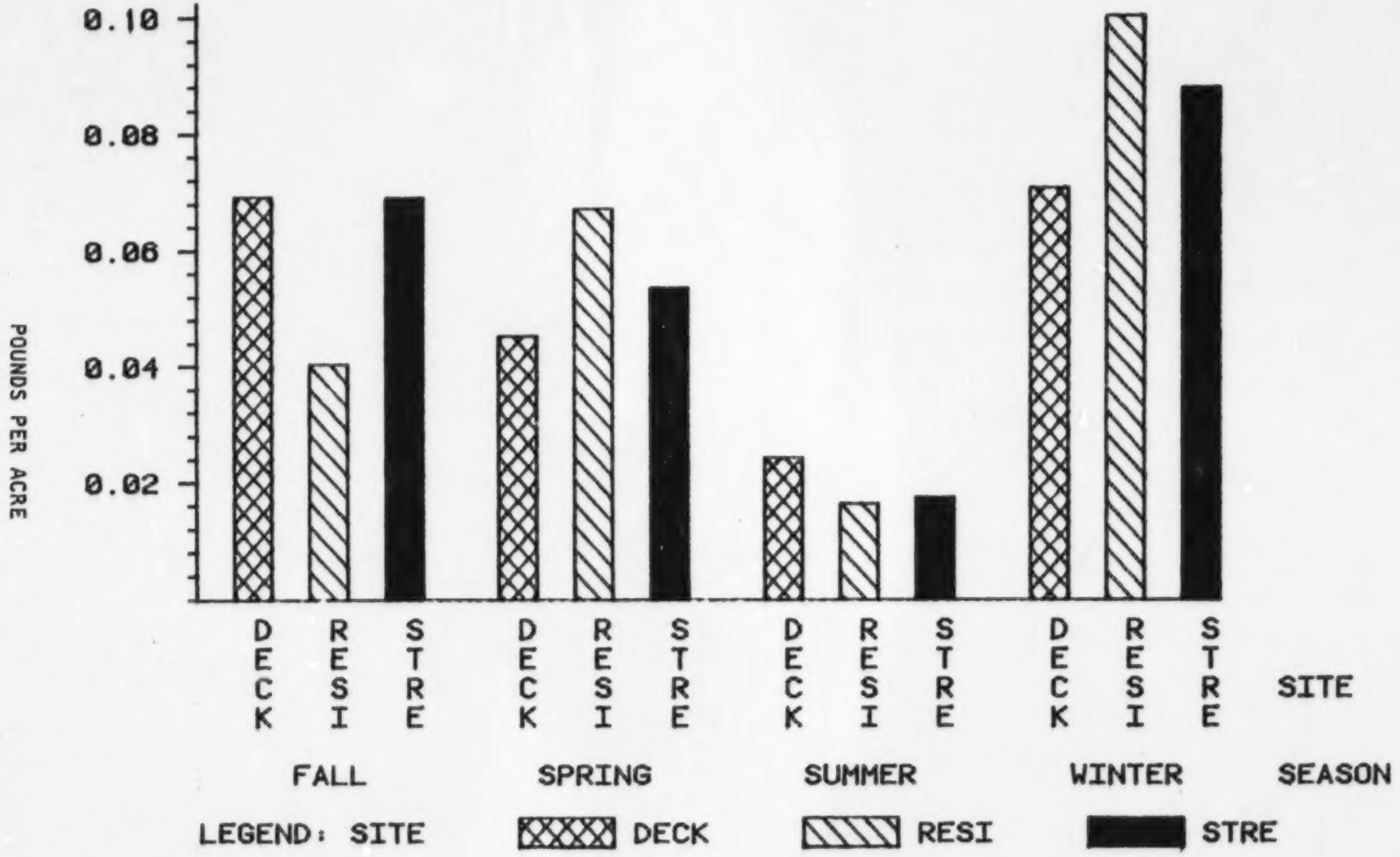


Figure 8

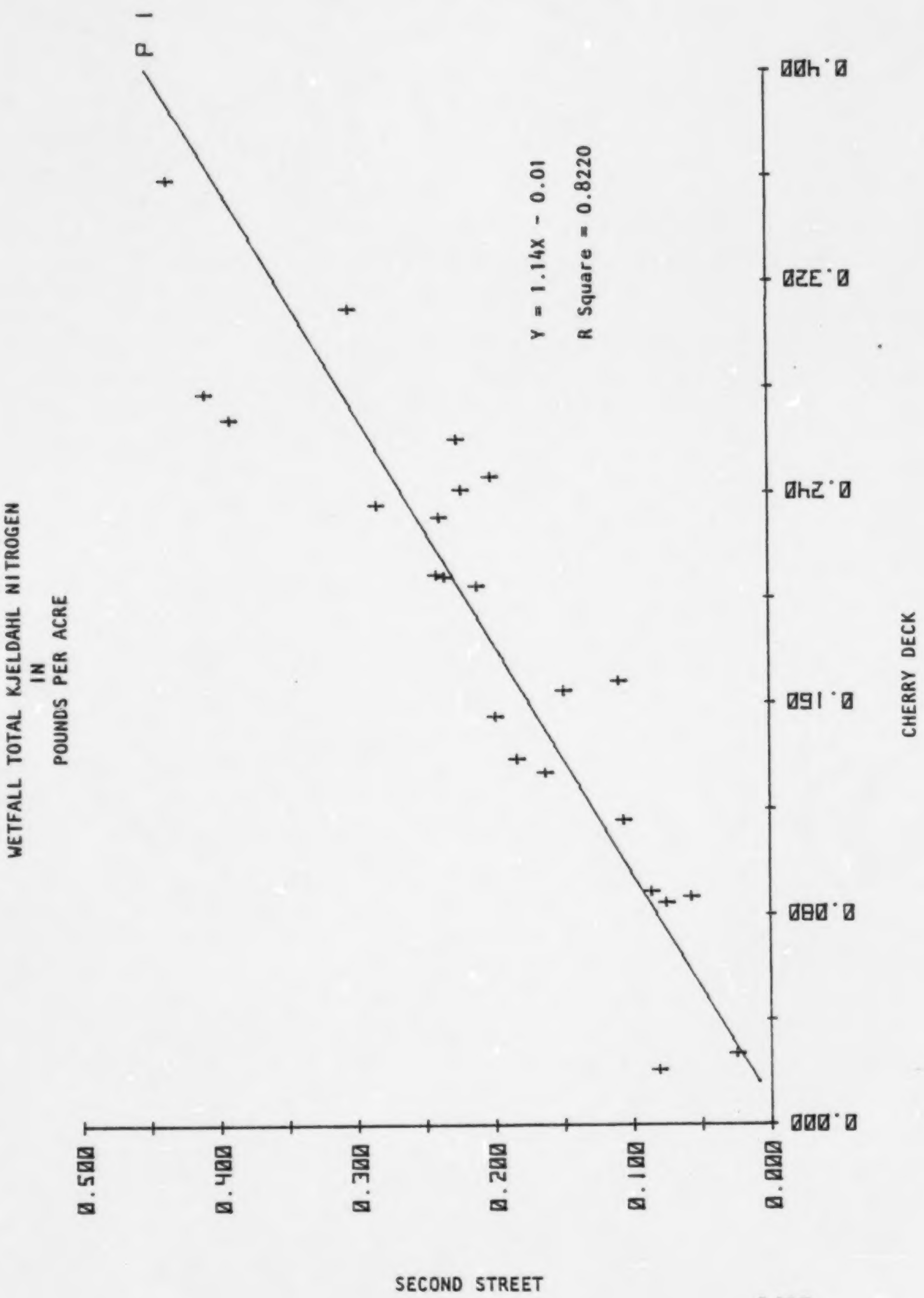

P I
Y = 1.14X - 0.01
R Square = 0.8220
WETFALL TOTAL KJELDAHL NITROGEN
IN
POUNDS PER ACRE
0.000
0.080
0.160
0.240
0.320
0.400
CHERRY DECK
0.000
0.100
0.200
0.300
0.400
0.500
SECOND STREET

Figure 9

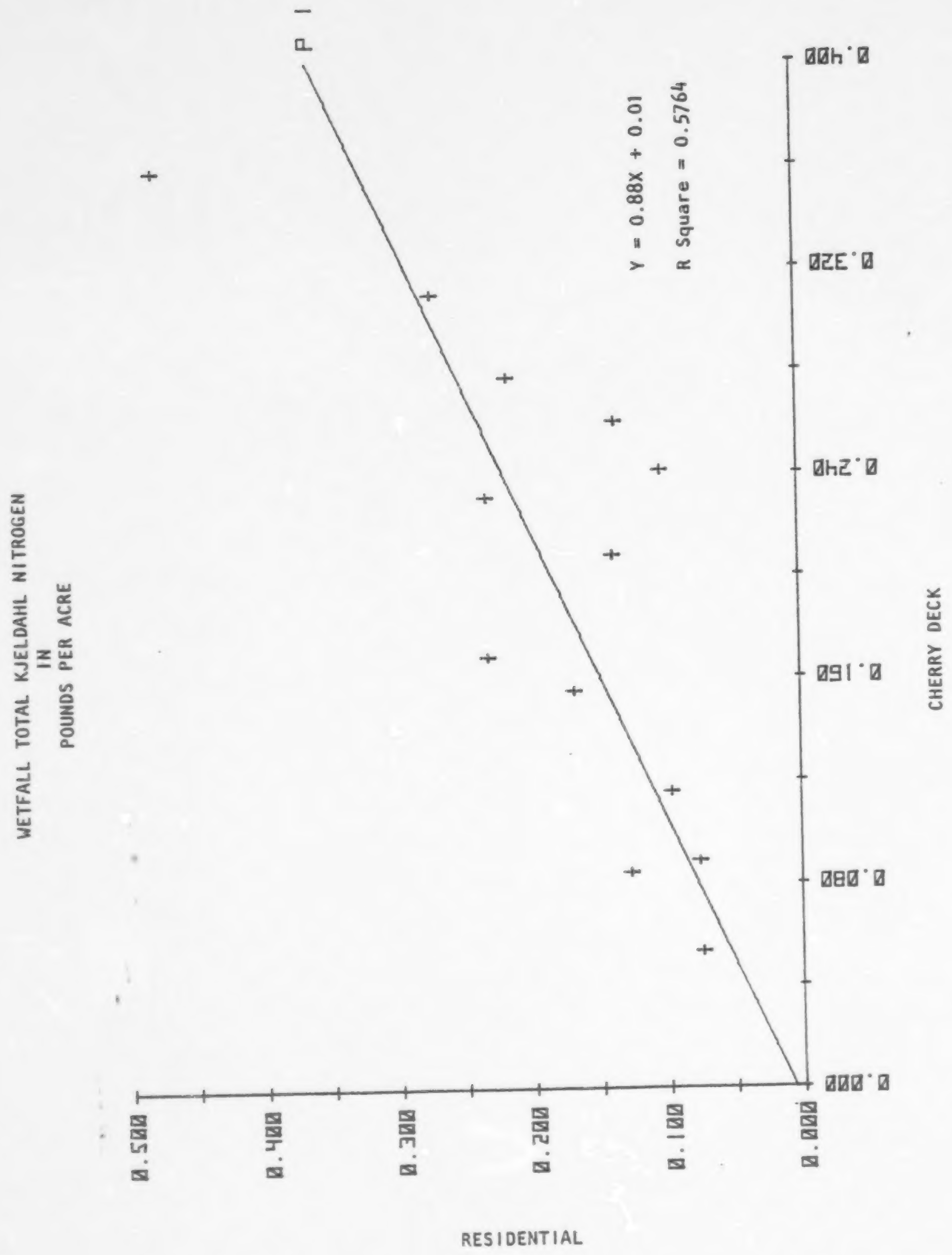

WETFALL TOTAL KJELDAHL NITROGEN
IN
POUNDS PER ACRE
P I
Y = 0.88X + 0.01
R Square = 0.5764
0.000
0.080
0.160
0.240
0.320
0.400
CHERRY DECK
0.500
0.400
0.300
0.200
0.100
0.000
RESIDENTIAL

Figure 10

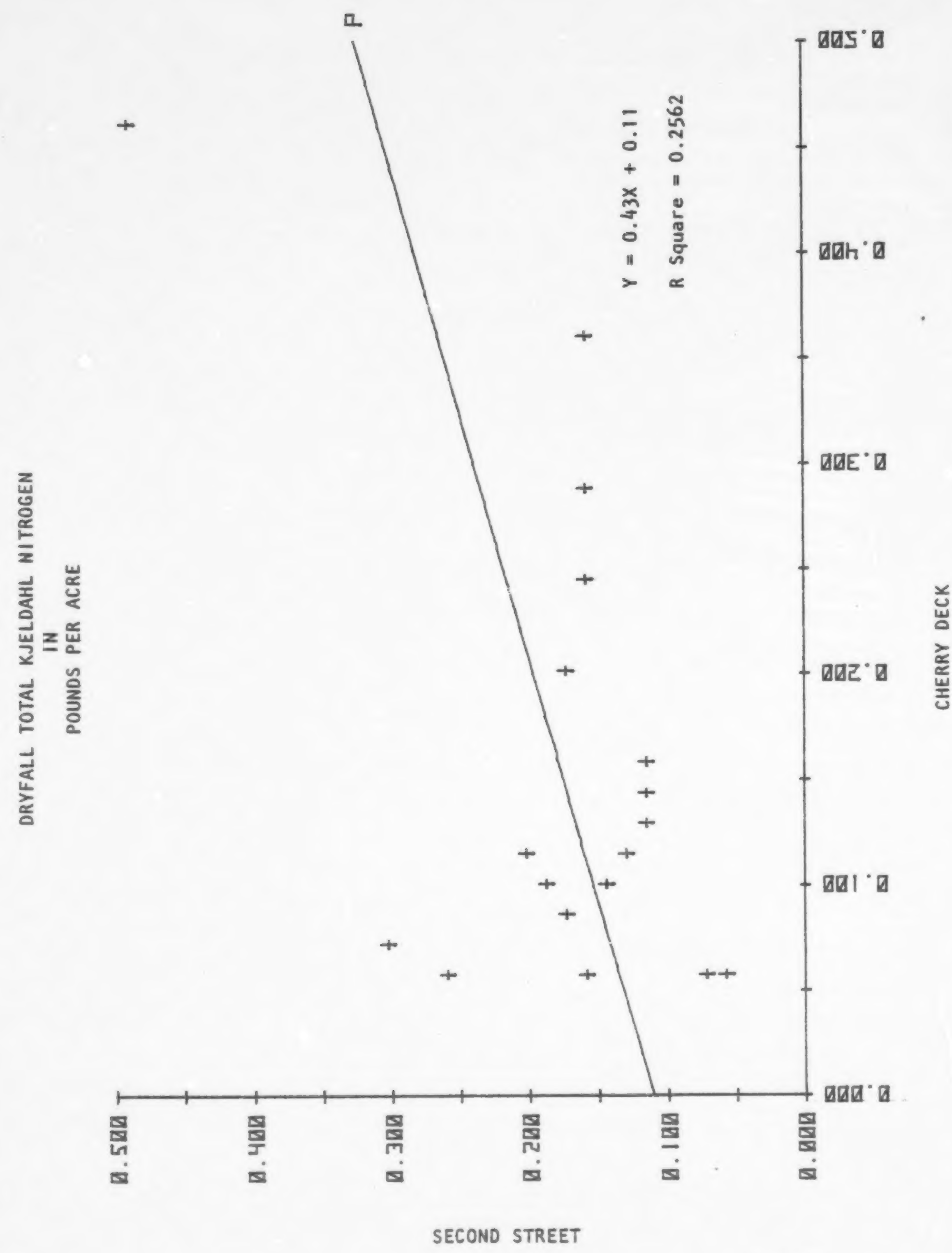

DRYFALL TOTAL KJELDAHL NITROGEN
IN
POUNDS PER ACRE
Y = 0.43X + 0.11
R Square = 0.2562
P I
CHERRY DECK
SECOND STREET
0.000
0.100
0.200
0.300
0.400
0.500

Figure 11

WETFALL TOTAL KJELDAHL NITROGEN - SEASONAL COMPARISONS
IN
POUNDS PER ACRE

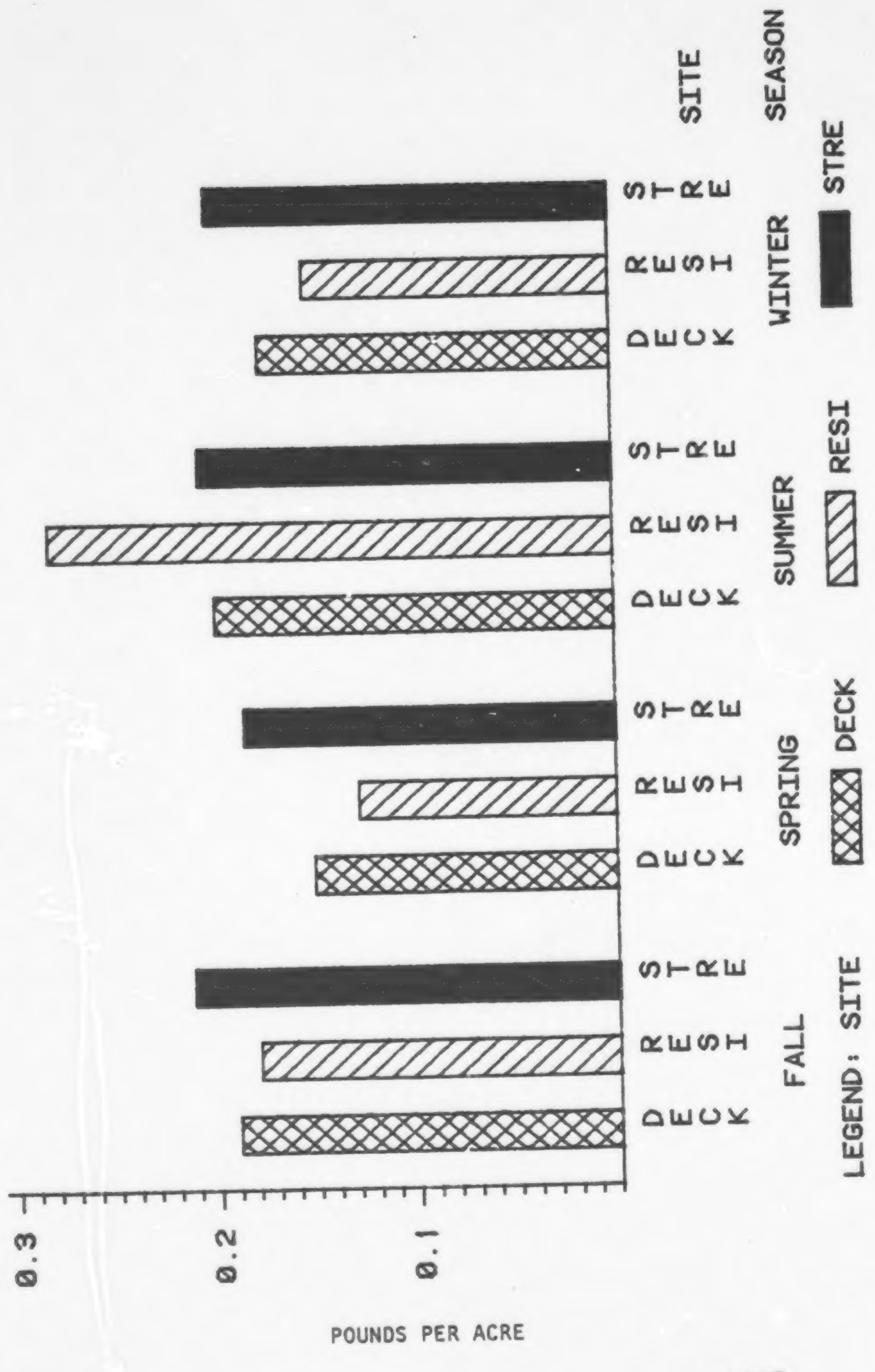
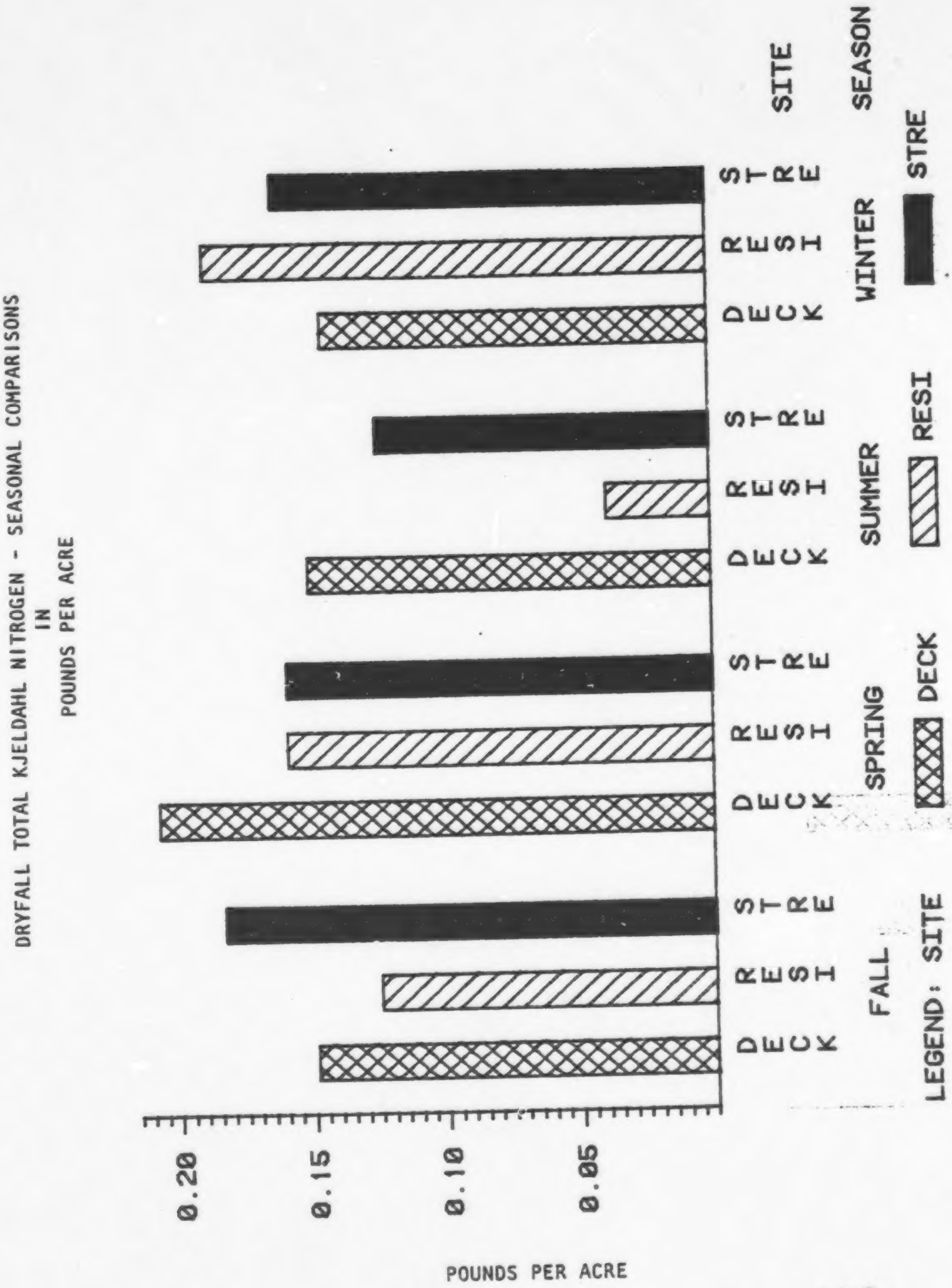


Figure 12



160

Figure 13

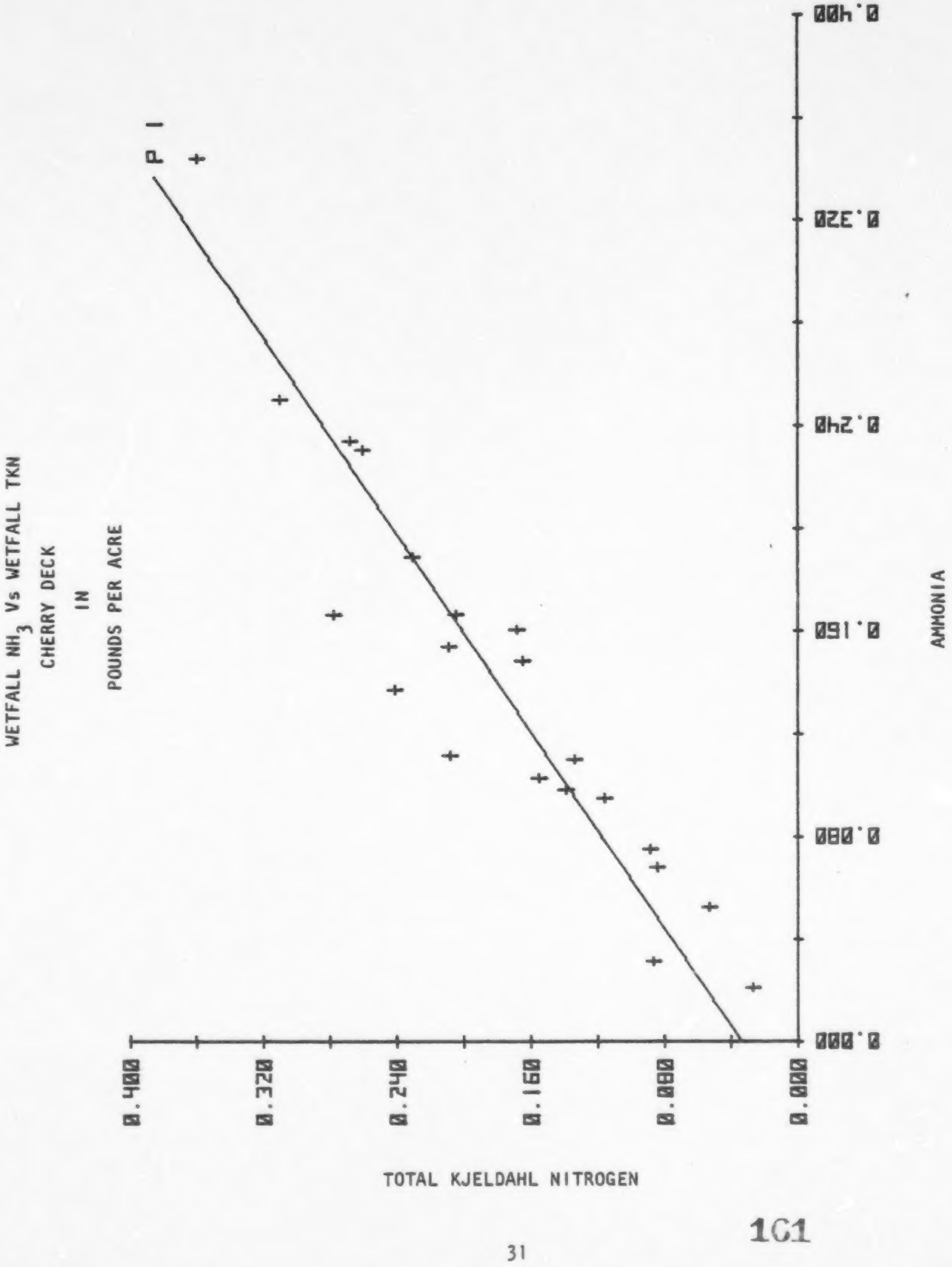
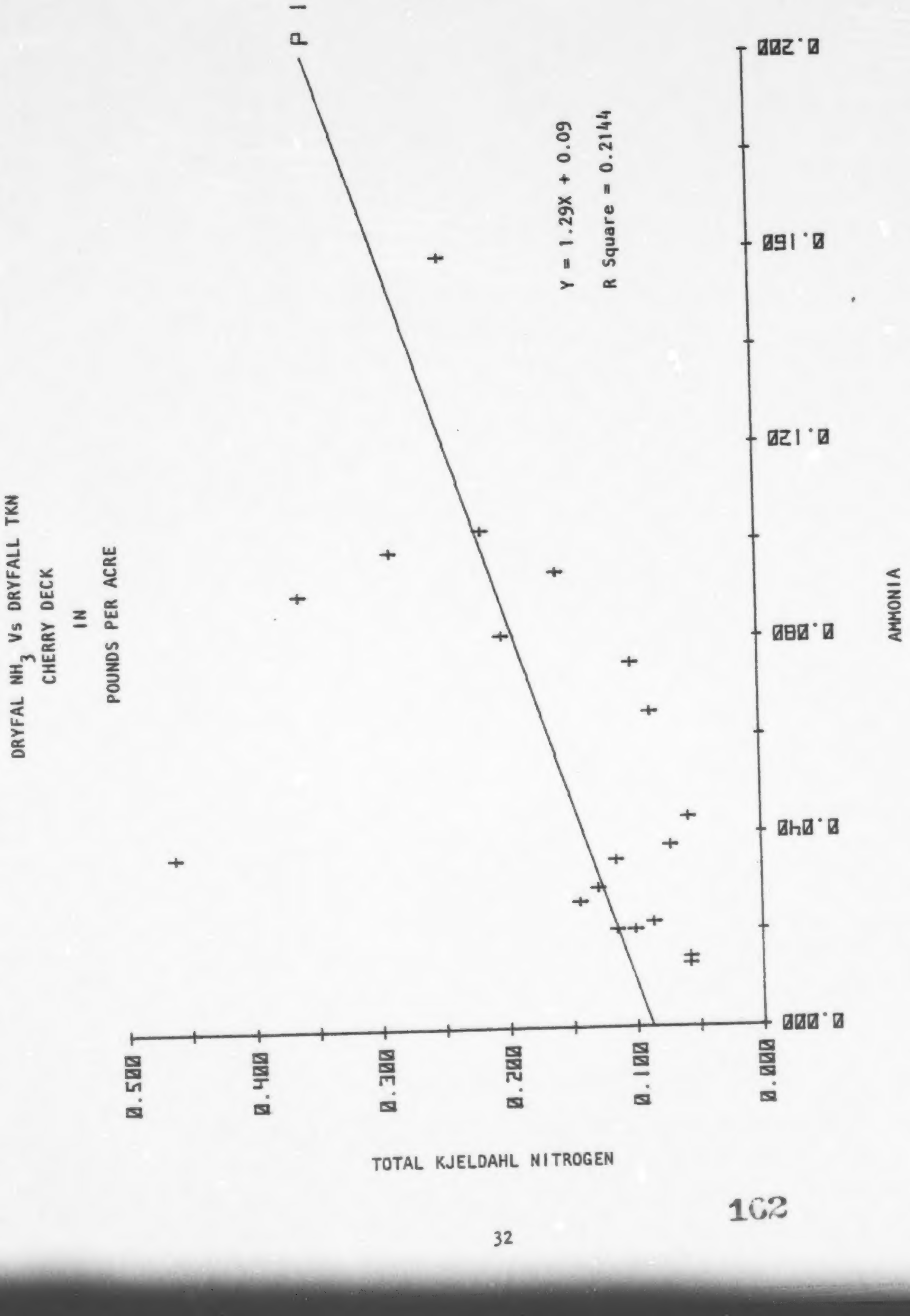

WETFALL NH_3 Vs WETFALL TKN
CHERRY DECK
IN
POUNDS PER ACRE
P
TOTAL KJELDAHL NITROGEN
0.400
0.320
0.240
0.160
0.080
0.000
AMMONIA
0.000
0.080
0.160
0.240
0.320
0.400

Figure 14



102

Figure 15

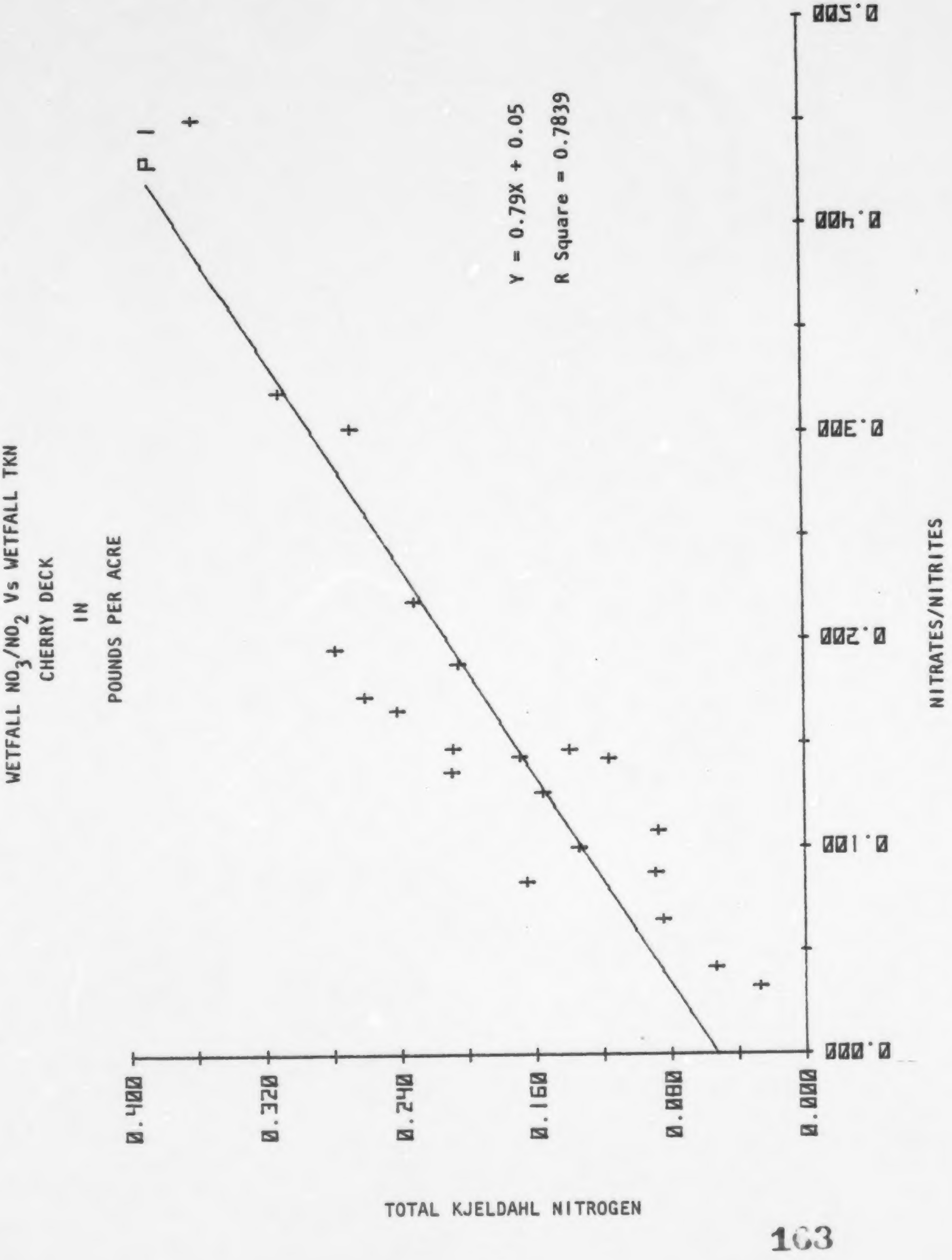

WETFALL NO_3/NO_2 Vs WETFALL TKN
CHERRY DECK
IN
POUNDS PER ACRE
Y = 0.79X + 0.05
R Square = 0.7839
P
NITRATES/NITRITES
0.000
0.100
0.200
0.300
0.400
0.500
TOTAL KJELDAHL NITROGEN
0.000
0.080
0.160
0.240
0.320
0.400

Figure 16

DRYFALL NO_3/NO_2 Vs DRYFALL TKN
CHERRY DECK
IN
POUNDS PER ACRE

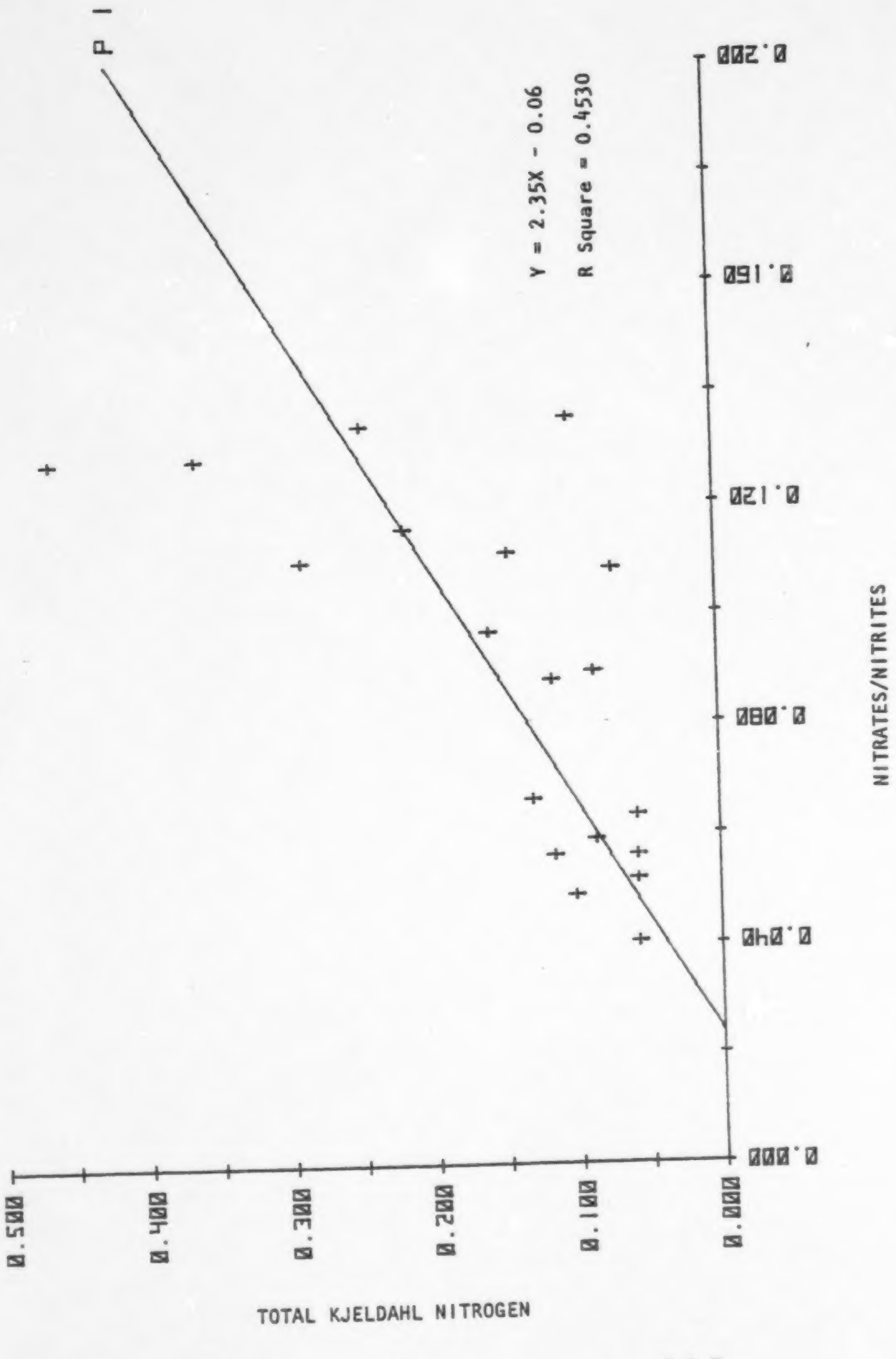


Figure 17

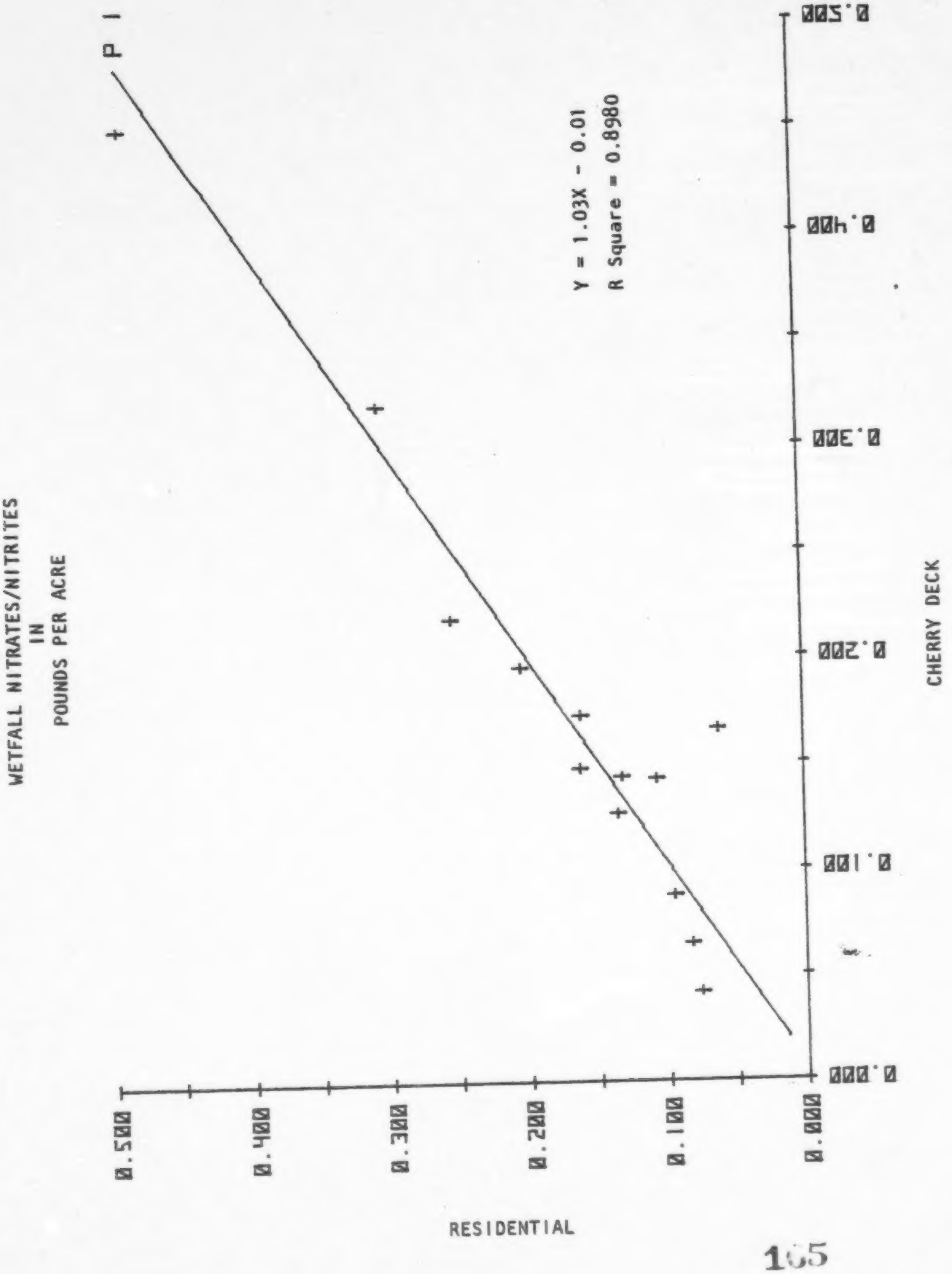

WETFALL NITRATES/NITRITES
IN
POUNDS PER ACRE
Y = 1.03X - 0.01
R Square = 0.8980
P I
CHERRY DECK
0.000
0.100
0.200
0.300
0.400
0.500
RESIDENTIAL
0.000
0.100
0.200
0.300
0.400
0.500

Figure 18

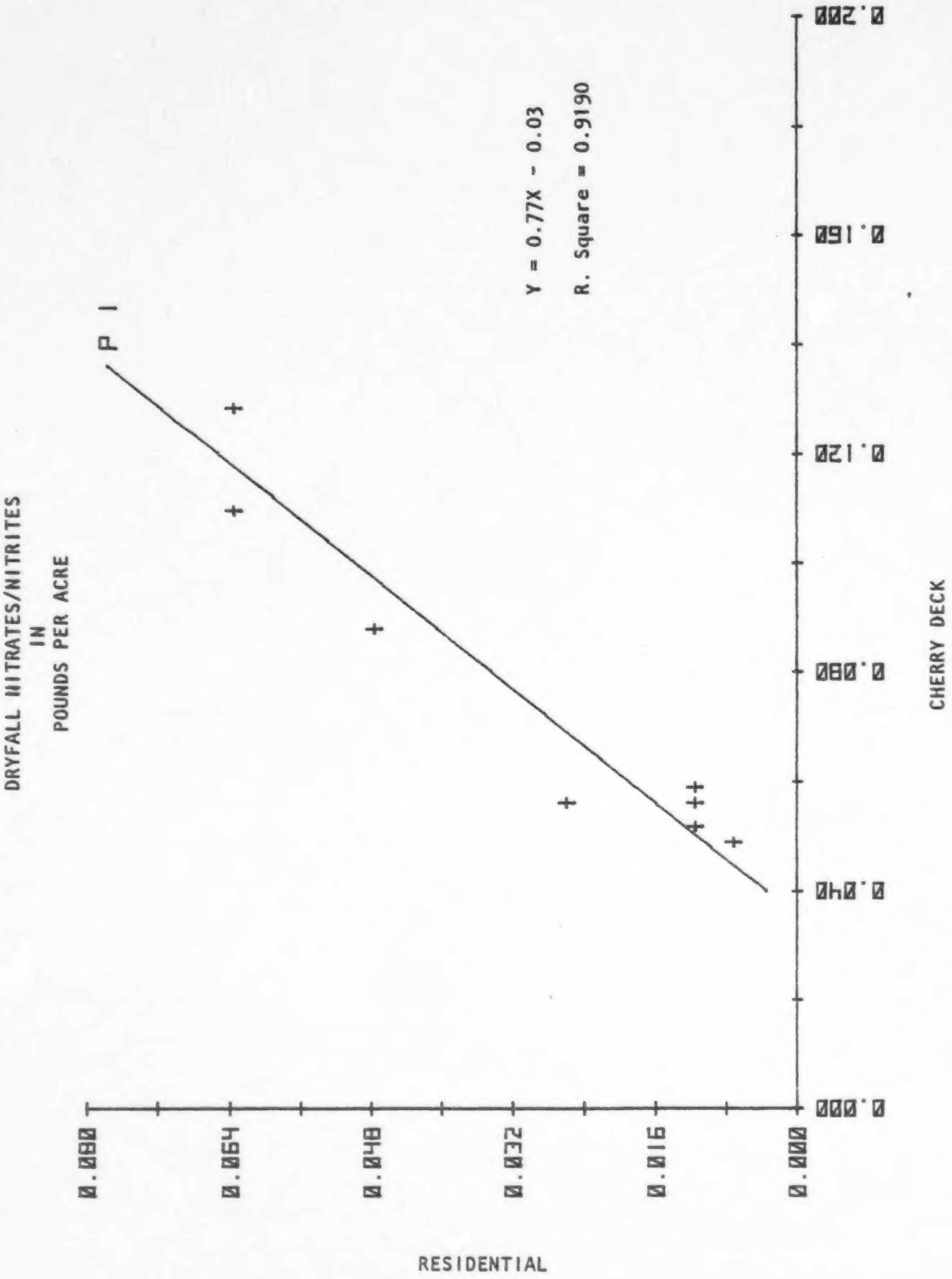

DRYFALL NITRATES/NITRITES
IN
POUNDS PER ACRE
Y = 0.77X - 0.03
R. Square = 0.9190
P
CHERRY DECK
RESIDENTIAL
0.000
0.016
0.032
0.048
0.064
0.080
0.000
0.040
0.080
0.120
0.160
0.200

Figure 19

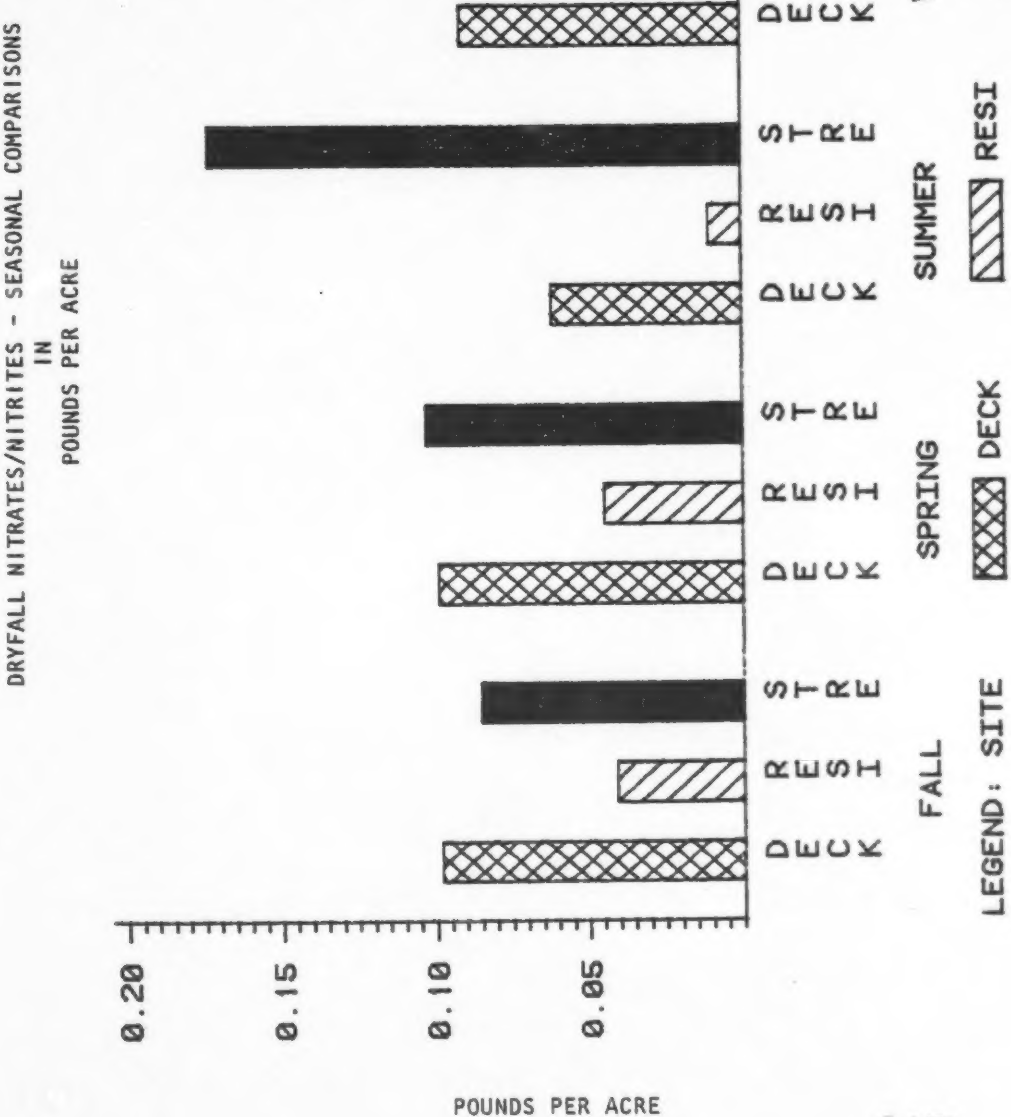

DRYFALL NITRATES/NITRITES - SEASONAL COMPARISONS
IN
POUNDS PER ACRE
0.20
0.15
0.10
0.05
DECK
RESI
STRE
DECK
RESI
STRE
DECK
RESI
STRE
DECK
RESI
STRE
SITE
FALL
SPRING
SUMMER
WINTER
SEASON
LEGEND: SITE
DECK
RESI
STRE
POUNDS PER ACRE

Figure 20

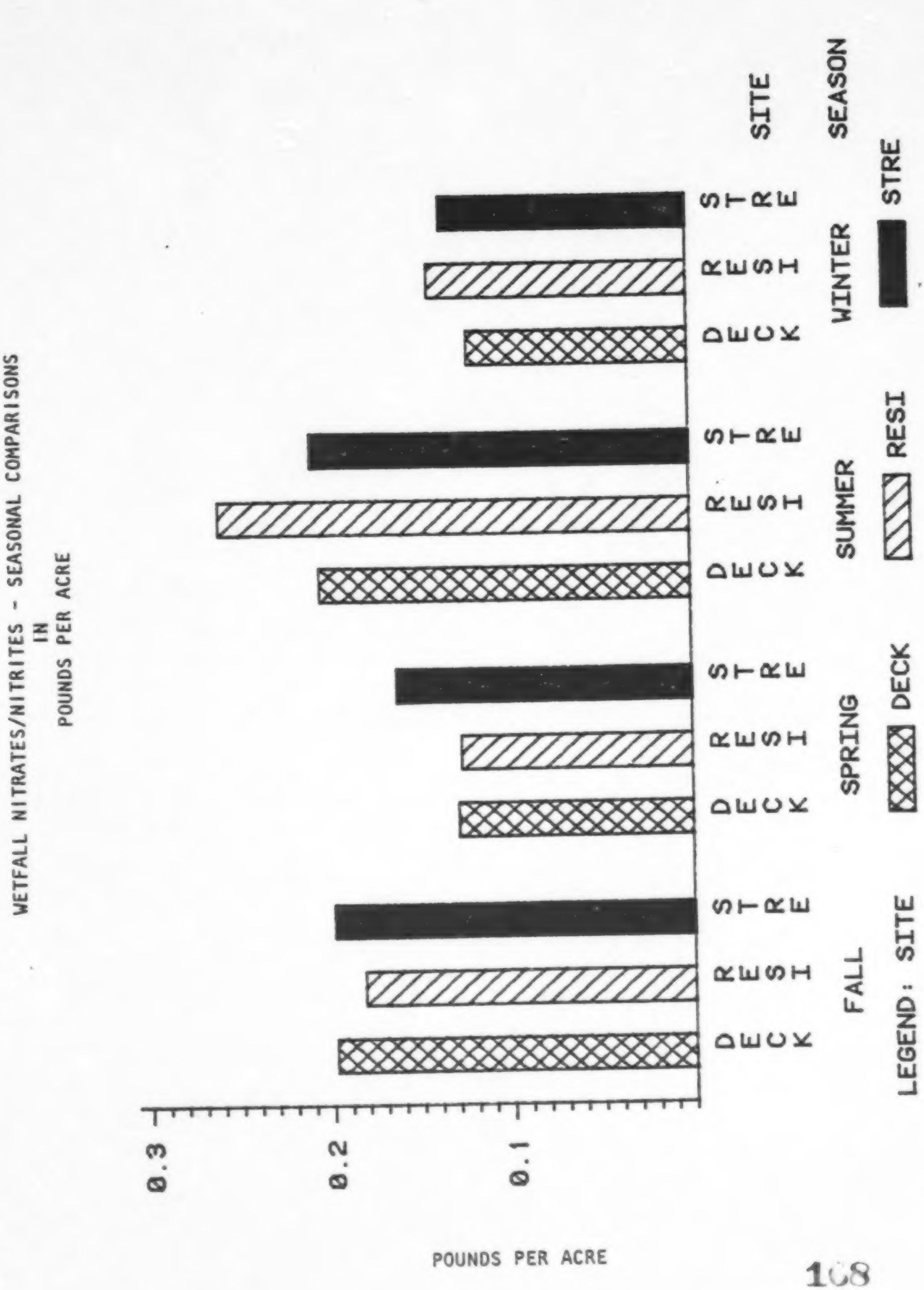
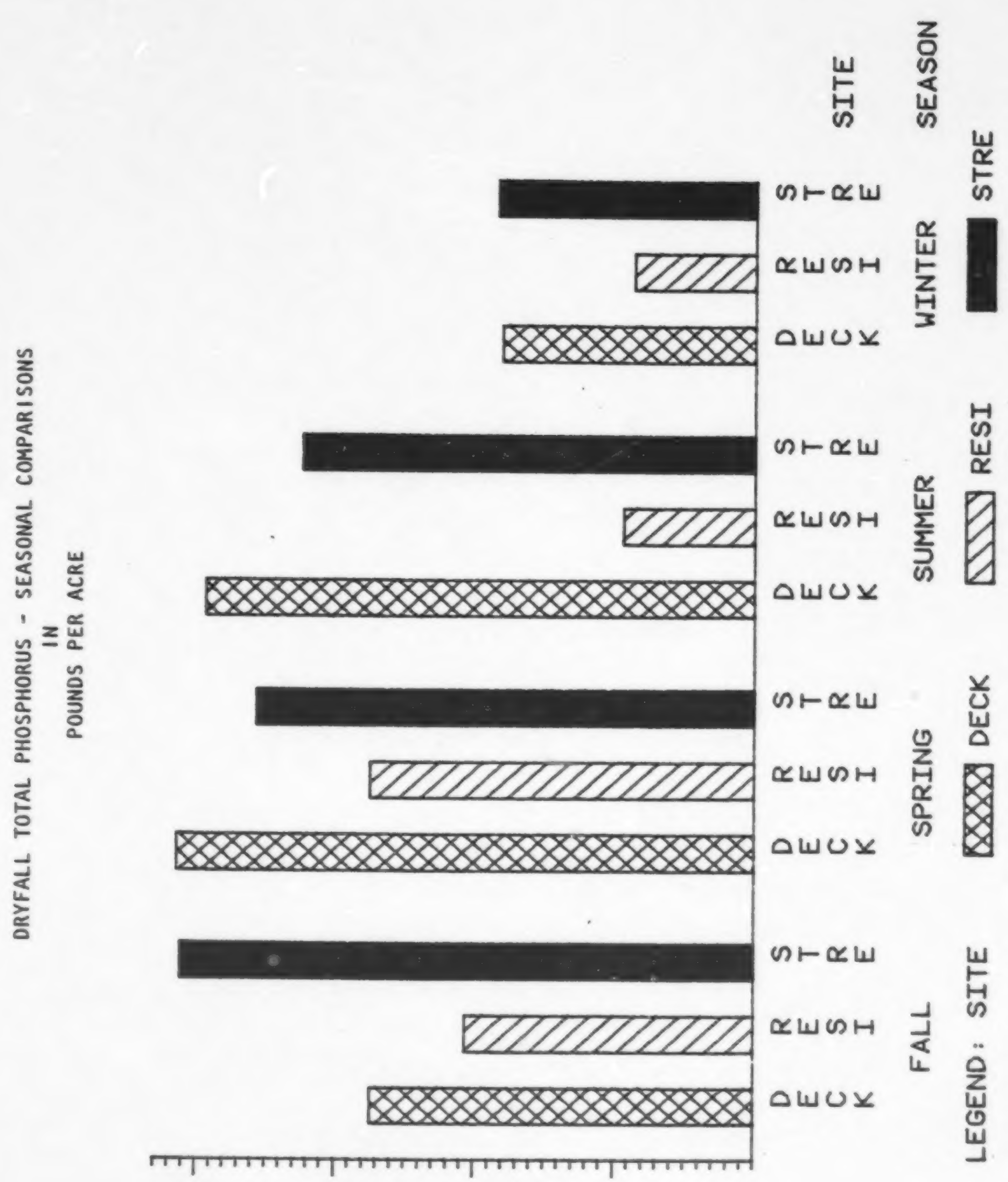

WETFALL NITRATES/NITRITES - SEASONAL COMPARISONS
IN
POUNDS PER ACRE
0.3
0.2
0.1
POUNDS PER ACRE
DECK
RESI
STRE
FALL
SPRING
SUMMER
WINTER
SITE
SEASON
LEGEND: SITE
DECK
RESI
STRE

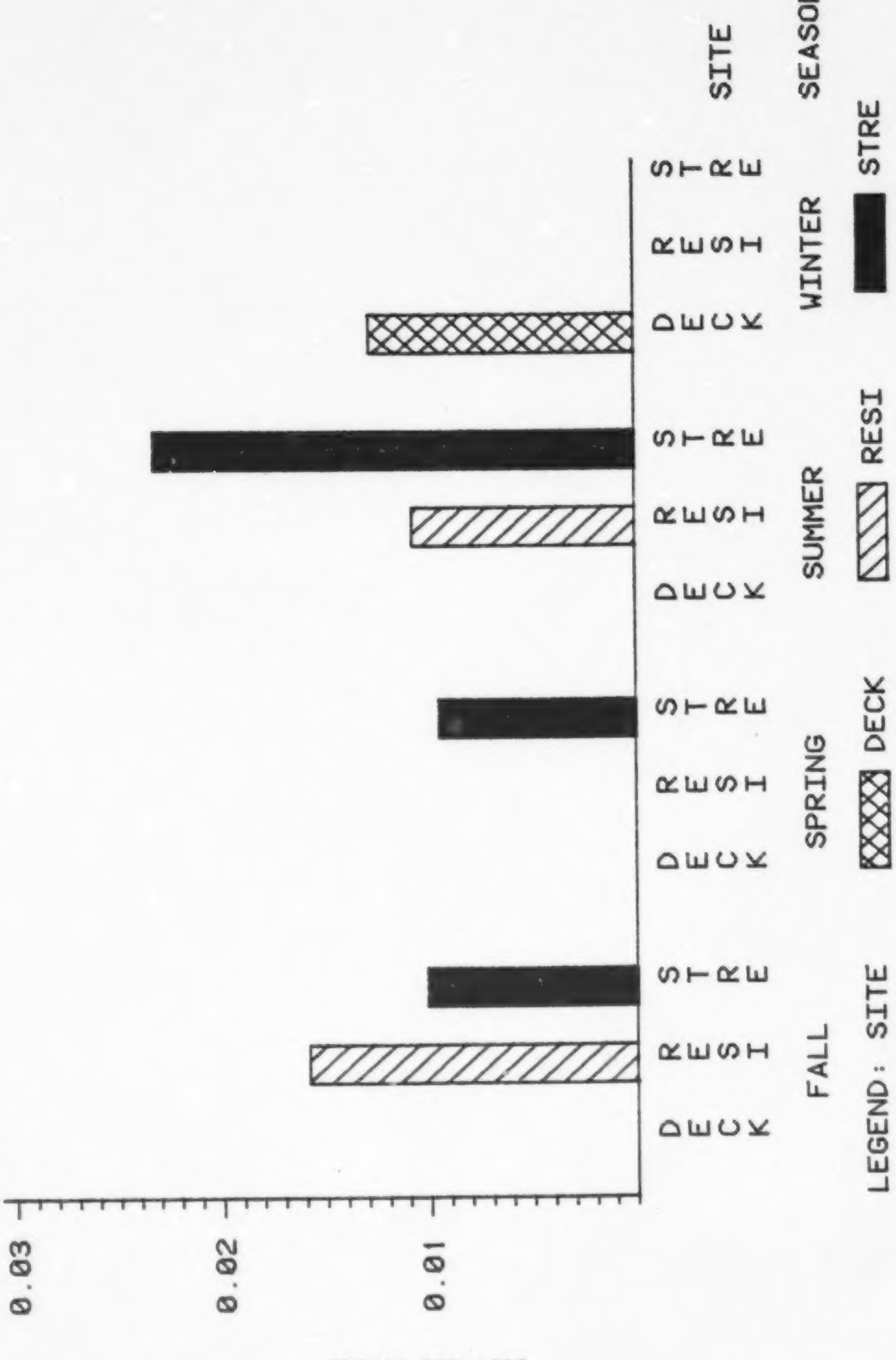
Figure 21



DRYFALL TOTAL PHOSPHORUS - SEASONAL COMPARISONS IN POUNDS PER ACRE

Figure 22

WETFALL TOTAL PHOSPHORUS - SEASONAL COMPARISONS
IN
POUNDS PER ACRE



ATMOSPHERIC DEPOSITION ANALYSIS - METALS

Introduction

Deposition samples from all three monitoring sites were analyzed for nine metals: copper, lead, zinc, mercury, cadmium, cobalt, chromium, manganese, and nickel. Of these pollutants, only four were present in concentrations above the minimum detectable limit - copper (Cu), zinc (Zn), lead (Pb), and mercury (Hg). The following discussion is based on analyses of monthly dryfall samples and monthly composited wetfall samples. Stations in the CBD provided twenty-two months of data, while the RES site data are derived from only fourteen months.

A summary of the observed pollutant loadings in each of the two sample types from all three monitoring stations is presented below, in Table 3.

Copper (Cu)

General:

Oxides and sulfates of copper are used in pesticides, algicides, and fungicides. Copper is frequently incorporated into paints and wood preservatives to inhibit growth of algae and invertebrate organisms (Shelley, 1979). Shaheen (1975) pointed out that most metals are used in parts of automobiles which are subject to wear, making vehicles one of the main sources of metals in the environment. The principal metal produced from engine wear is copper, from thrust bearings, bushings and other bearing metals. Brake linings are also rich in copper (Harrison, 1979).

Data analysis;

Paired t comparisons between watersheds for both wetfall and dryfall were unavailable due to the overall lack of measured copper, particularly in the Res watershed. As stated above, the primary source of copper in this area may be automobile related and as such, the difference in traffic density between the two watersheds may account for this disparity. The incidence of dryfall copper deposition in the CBD watershed (Cherry Deck and Second Street), however, did indicate a localized trend for the few comparable months, having a significant correlation at the .05 level ($r^2_{[4]} = .7402$, Figure 23).

Seasonal comparisons of dryfall copper (Figure 24) demonstrated both the similarity of its deposition at the two sites in the CBD watershed and also its relative lack in the Res watershed. Seasonal wetfall copper values (Figure 25) were highest in the CBD watershed, some average monthly values surpassing the dryfall values. Due to the relative scarcity and intermittent occurrence of this pollutant in the sampled wetfall, however, this data should be reviewed with caution.

Zinc (Zn)

General:

Zinc is a metal usually found in nature as zinc sulfide. It is used in galvanizing and in the preparation of alloys for dye casting. It is a component of brass and bronze alloys, slush castings, photoengraving, printing plates, silver and stainless steel tableware, viscose rayon yarn, wood pulp and newsprint paper. Other sources include mining areas, paint pigments, cosmetics, pharmaceutics, and insecticides (Shelley, 1979). Additionally, zinc is considered to be a traffic related pollutant. This metal is a component of rubber tires, as well as being a major constituent of motor oil (Harrison, 1979).

Data analysis:

Paired sample t-tests of the Zn dryfall data indicated significantly higher values at both CBD sites when each was compared with the RES site (Cherry Deck, $t_{.005[9]} = 4.174$; Second Street, $t_{.001[9]} = 5.893$). This difference could be expected, given the greater traffic density in the CBD watershed. Additionally, street level dryfall amounts of Zn were found to be significantly higher than those on the Cherry Deck ($t_{.05[19]} = 2.418$). This relationship is also understandable considering that the Second Street monitor was at ground level and directly adjacent to the street, while the Cherry Deck monitor was somewhat removed from the street and four stories high. Zinc was detected in every monthly dryfall sample analyzed, from all three stations, while being measurable in only 18% of the monthly rainfall composites.

In the seasonal wetfall comparisons of zinc, there appears to be an extremely high concentration in the winter months at the Second Street station (Figure 26). This peak may be biased, in that one sample collected at that station, in December of 1981, was reported as 410 µg/l. This one value is approximately eight times higher than the other Zn values measured in that season. As the other metals analyzed in that sample fell below their detectable limits, it is possible that the reported zinc componant was introduced through contamination, or was simply misrecorded.

A strong linear correlation was indicated between the lead deposition and the Zn deposition within the overall dryfall composites (all stations combined) ($r^2_{.001[38]} = .5100$; Figure 28), with an even higher correlation between them (Zn with Pb) on the data collected at the Second Street station ($r^2_{.001[19]} =$

.5268, Figure 29). This similarity in deposition might be expected, as both lead and Zn are considered traffic related pollutants.

Lead (Pb)

General:

Lead and its compounds are commonly found in nature. It is used in the manufacture of storage batteries, television tubes, pringing, paint pigments, fuels, photographic materials, pesticiedes, and explosives. Lead components of plumbing systems are another source of the metal (Shelley, 1979).

Data analysis:

While measurable amounts of lead were present in approximately 90% of the dryfall samples (100% at the Second Street site), the metal was detected in only 6% of the wetfall events. No significant differences were established between dryfall and wetfall amounts of the pollutant since there were too few paired samples available for comparison. Dryfall amounts of lead were significantly higher at the street side than at either of the other two sites (Deck, $t_{.01[17]} = 3.183$; RES, $t_{.01[3]} = 7.000$). Linear correlation analysis of dry samples from the two CBD sites showed no significance (Figure 30; $r^2_{.5[17]} = .0064$), indicating that the sources are impacting the two sites differently. The proximity of the Second Street monitor to automobile traffic may explain this difference.

As explained in the previous section, a strong linear correlation was found between zinc and lead in dryfall samples throughout the study, particularly at the Second Street site. This adds validity to the hypothesis that traffic had a greater impact on the street-side site than on the Cherry Deck or RES sites.

Seasonal comparisons of dryfall lead amounts display the predominance of the pollutant in the CBD over the residential watershed. Samples from the Second Street site tend to contain more lead than those from the Cherry Deck, particularly in the fall and winter. Wetfall samples were inconclusive on a seasonal basis due to the small number of samples having measurable amounts of lead.

Mercury (Hg)

General:

Mercury is widely distributed in the environment, and biologically is a nonessential or nonbeneficial element. Discharged mercury does not remain localized. It can enter the environment by seeping up through layers of earth to the surface, outgassing of Hg from rock and soil, and transport by natural cycles. Most industrial mercury is eventually lost as waste into streams or the atmosphere. Uses of Hg include the electrical and chlor-alkali industry application, industrial control equipment, paints, agriculture, dental preparations, pulp and paper industry, catalysts in chemical manufacturing processes, and general laboratory uses (Shelley, 1979).

Data analysis:

Monthly Hg dryfall values were measured above the detectable limit in 51% of the total CBD samples collected and only 23% of the RES samples collected. Within the CBD, the Cherry Deck station monitored a 59% occurance of Hg, while the Second Street station monitored a 46% occurance. Paired t-comparisons of the intra-CBD monthly values showed a marginally significant difference between their amounts of dry Hg deposition ($t_{.10[5]} = 2.118$), with Cherry Deck levels being higher. A linear correlation of these CBD monthly dry Hg values was significant at the .01 level, $r^2_{[6]} = .7198$ (Figure 33). Inter-watershed t-comparisons of the monthly dry Hg data was not possible due to the lack of paired values. The incidence of measurable Hg in the monitored wetfall events was even less evident than in the dryfall (Cherry Deck, 27%; Second Street, 13%; RES, 12%), and as such, no intra- or inter-watershed wetfall comparions were possible.

The seasonal distributions of monthly dryfall Hg data (Figure 34) demonstrate the considerable disparity between the CBD monitored levels and the RES monitored levels. Additionally, the possible predominance of the Cherry Deck site over the Second Street site, relative to this pollutant, is also apparent.

Wetfall Hg amounts, as mentioned above, were infrequent in their occurence, and as such, the monthly composited wetfall levels are considerably below those of the dryfall. As can be seen from the seasonal distribution of the wetfall Hg data (Figure 35), the incidences of its occurence are fairly constant throughout both watersheds. The one exception to this consistency is the elevated Residential winter distribution, which upon closer examination, has resulted from one exceedingly high Hg value (10 micrograms per liter, approximately 50 times the project mean). Considering that mercuric chloride is used as a preservative in the handling of wetfall nutrient samples, and also that these samples are prepared in close proximity to the metals samples, it is highly possible that this extreme Hg value was the result of laboratory cross contamination.

Table 3

MONTHLY RANGES, MEANS AND STANDARD DEVIATIONS OF OBSERVED LOADINGS OF METAL CONSTITUENTS WETFALL AND DRYFALL SAMPLES (LBS x 10^{-3}/ACRE

Pollutant	Station	Range of Observations		Mean		Std. Dev.		Number of Monthly Samples With Detected Amounts	
		Wetfall	Dryfall	Wetfall	Dryfall	Wetfall	Dryfall	Wetfall	Dryfall
Cu	Deck	2.079-15.368	5.764-8.645	7.187	6.304	5.799	1.072	5	8
	Street	.135-12.656	5.765-7.204	4.704	6.000	4.029	.588	5	7
	Res	4.068-8.814	-	5.83	-	2.60	-	3	0
Zn	Deck	5.424-29.380	10.086-73.487	11.639	30.331	8.878	12.329	4	21
	Street	1.356-287.246	17.291-56.196	51.192	34.798	104.366	10.127	3	21
	Res	6.916-8.588	10.086-17.291	7.751	14.089	1.182	2.134	2	10
Pb	Deck	.339-80.456	14.409-86.454	25.299	33.622	24.386	17.121	5	18
	Street	2.260-87.010	14.409-72.146	32.499	42.507	33.364	13.610	3	21
	Res	9.718-58.760	14.409-14.409	34.239	14.409	34.678	0	2	4
Hg	Deck	.034-.985	.072-.490	.203	.175	.287	.116	8	11
	Street	.024-.660	.029-.245	.188	.094	.219	.061	4	9
	Res	.095-5.130	.072-1.297	1.371	.101	2.506	.029	4	3

NOTE: Central business district data (Deck and Street) are derived from twenty-one months of sampling, while residential (Res) data represent thirteen months of sampling.

Figure 23

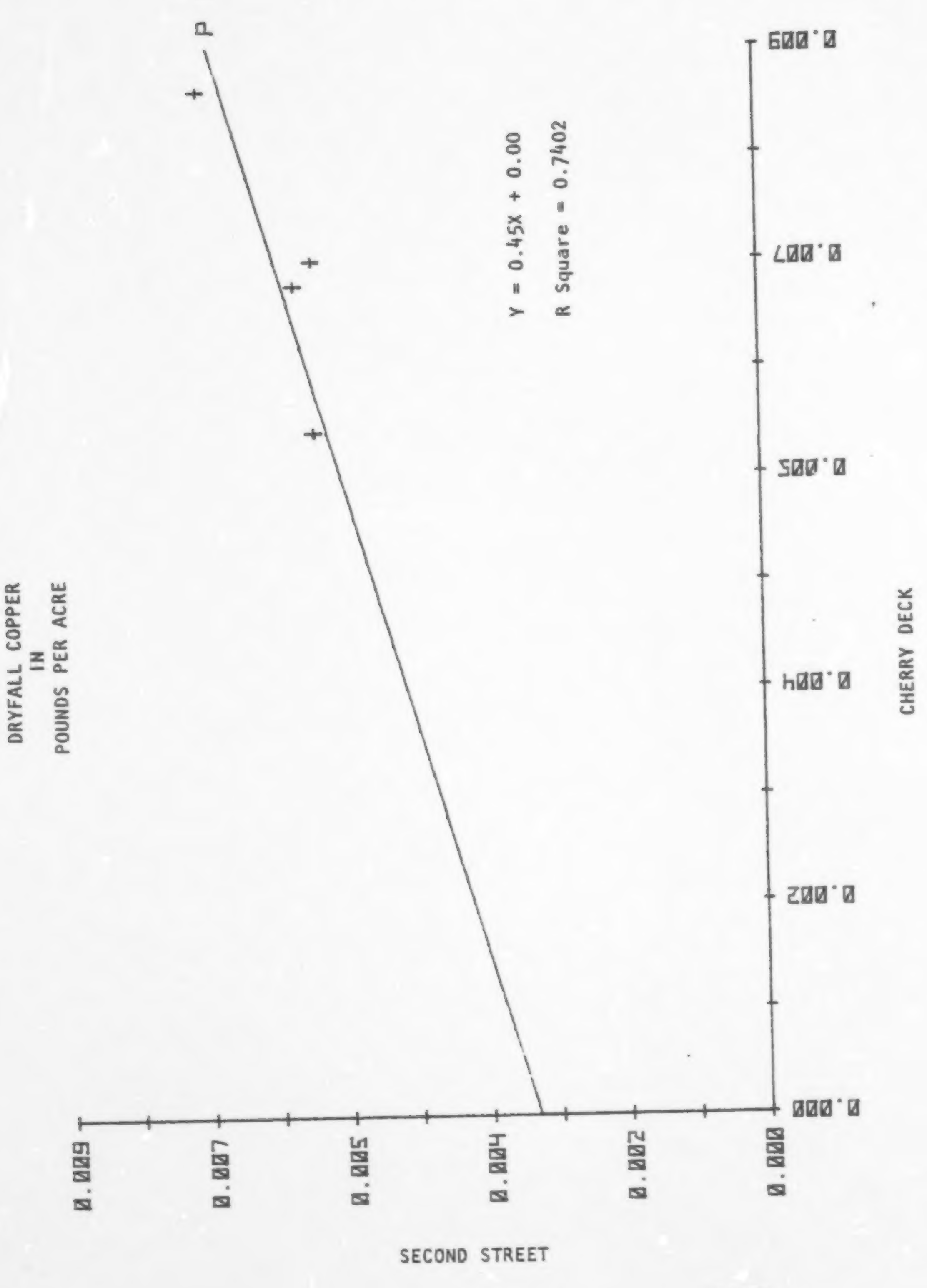
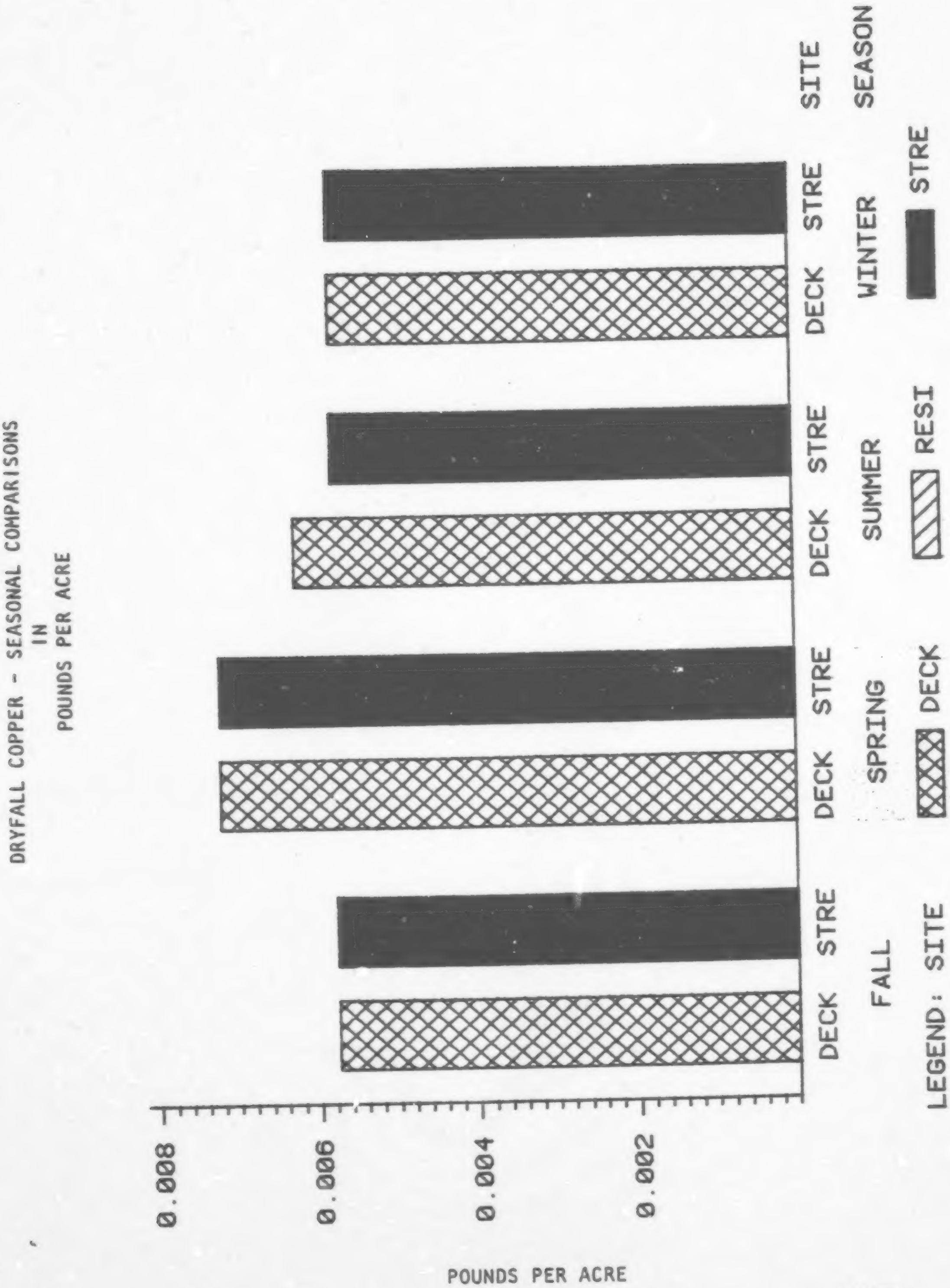

DRYFALL COPPER
IN
POUNDS PER ACRE
Y = 0.45X + 0.00
R Square = 0.7402
P
CHERRY DECK
0.009
0.007
0.005
0.004
0.002
0.000
0.009
0.007
0.005
0.004
0.002
0.000
SECOND STREET

Figure 24



DRYFALL COPPER - SEASONAL COMPARISONS
IN
POUNDS PER ACRE
0.008
0.006
0.004
0.002
POUNDS PER ACRE
DECK
STRE
FALL
SPRING
SUMMER
WINTER
SITE
SEASON
LEGEND: SITE
DECK
RESI
STRE

Figure 25

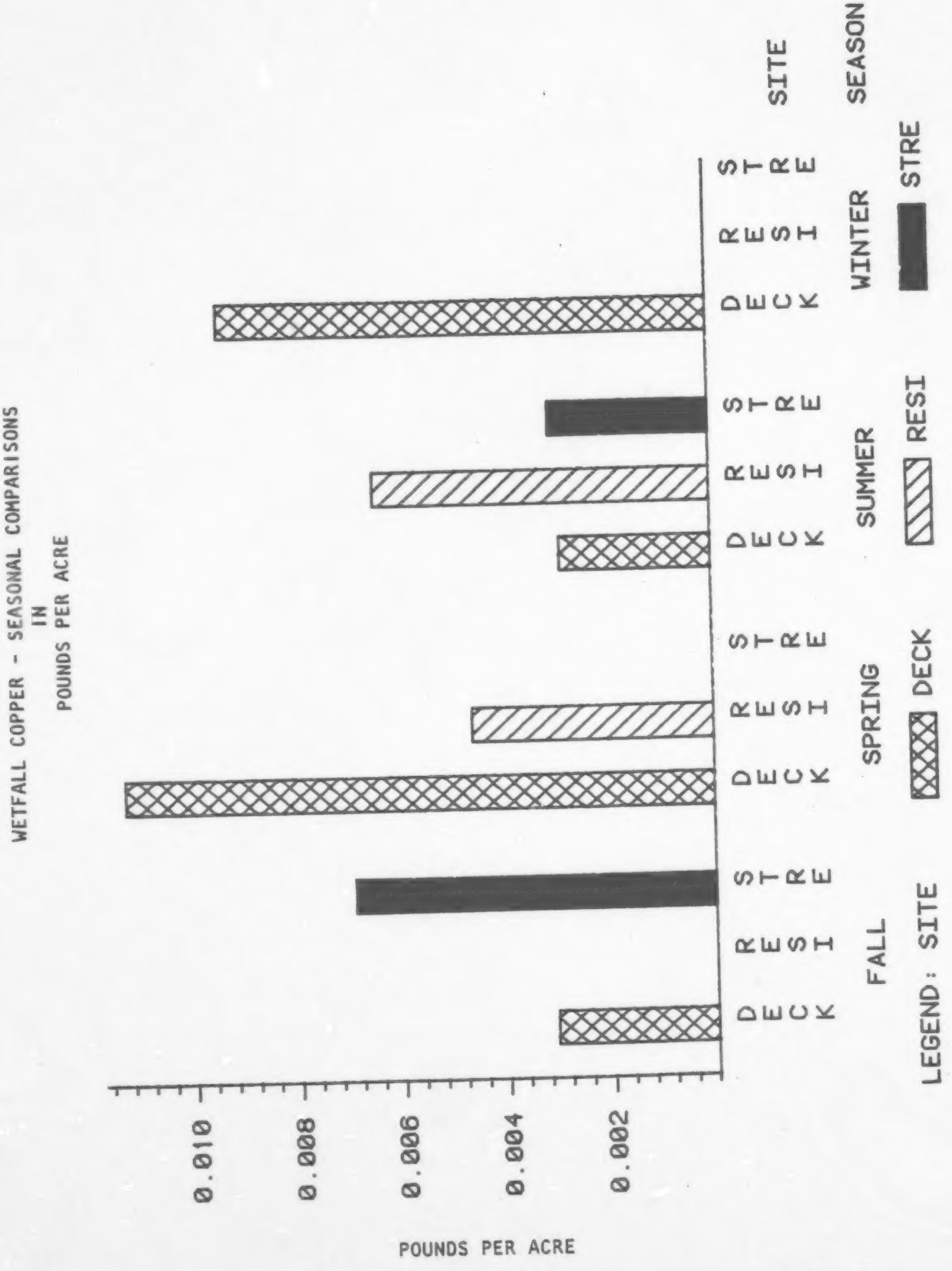

WETFALL COPPER - SEASONAL COMPARISONS
IN
POUNDS PER ACRE
POUNDS PER ACRE
0.010
0.008
0.006
0.004
0.002
DECK
RESI
STRE
FALL
SPRING
SUMMER
WINTER
SITE
SEASON
LEGEND: SITE
DECK
RESI
STRE

Figure 26

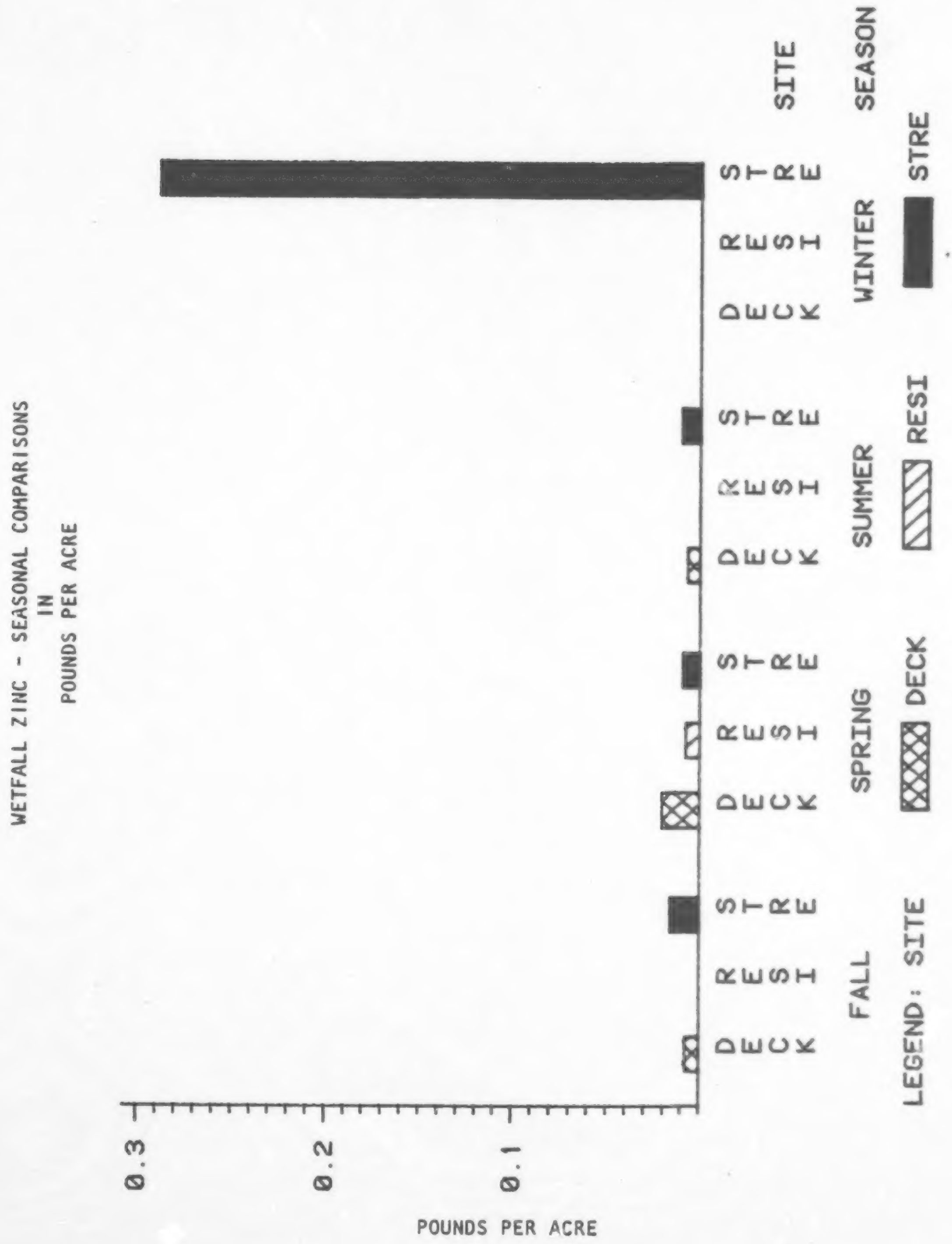

WETFALL ZINC - SEASONAL COMPARISONS
IN
POUNDS PER ACRE
POUNDS PER ACRE
0.3
0.2
0.1
DECK
RESI
STRE
DECK
RESI
STRE
DECK
RESI
STRE
DECK
RESI
STRE
SITE
FALL
SPRING
SUMMER
WINTER
SEASON
LEGEND: SITE
DECK
RESI
STRE

Figure 27

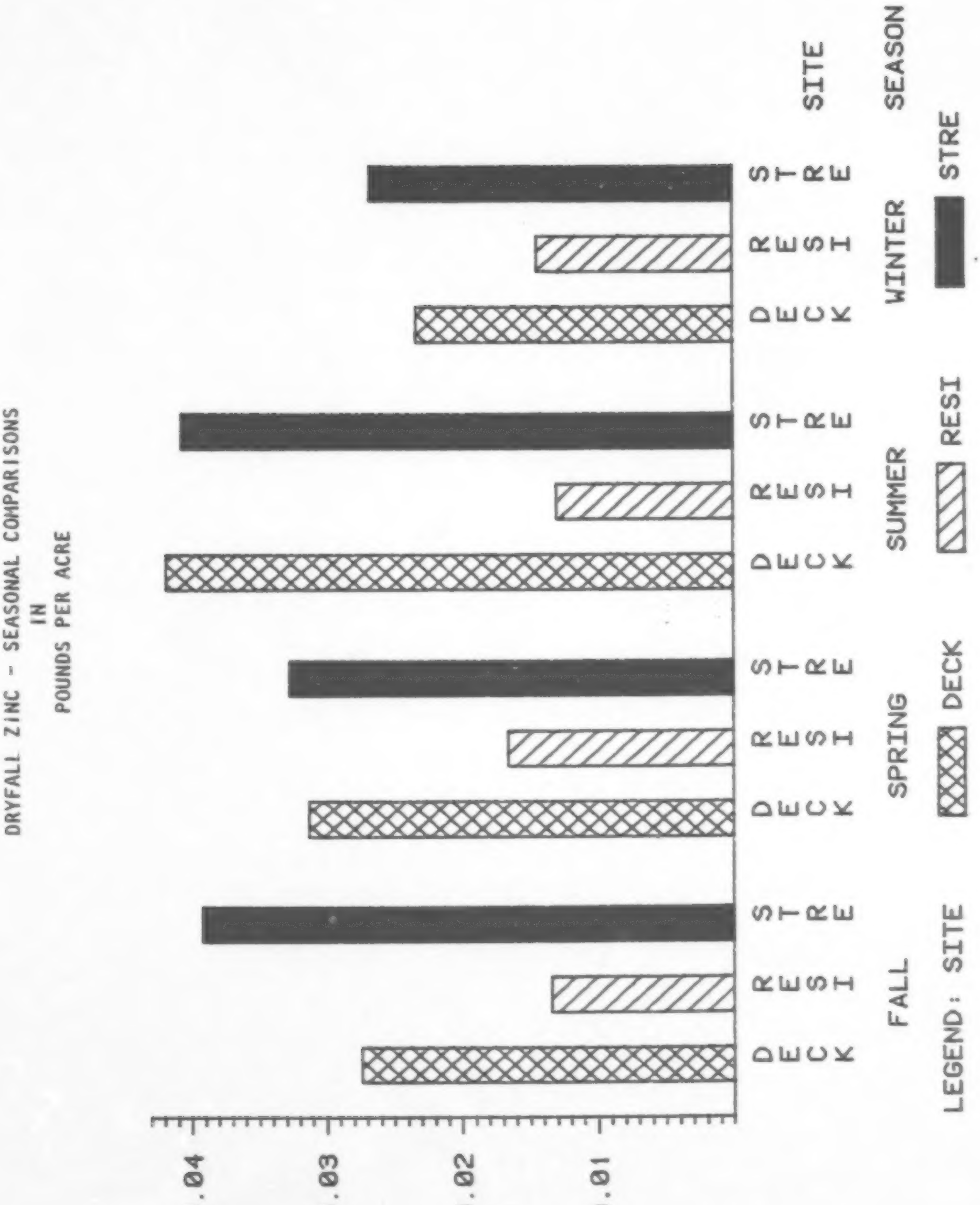

DRYFALL ZINC - SEASONAL COMPARISONS
IN
POUNDS PER ACRE
POUNDS PER ACRE
0.04
0.03
0.02
0.01
DECK
RESI
STRE
FALL
SPRING
SUMMER
WINTER
SITE
SEASON
LEGEND: SITE
DECK
RESI
STRE

Figure 28

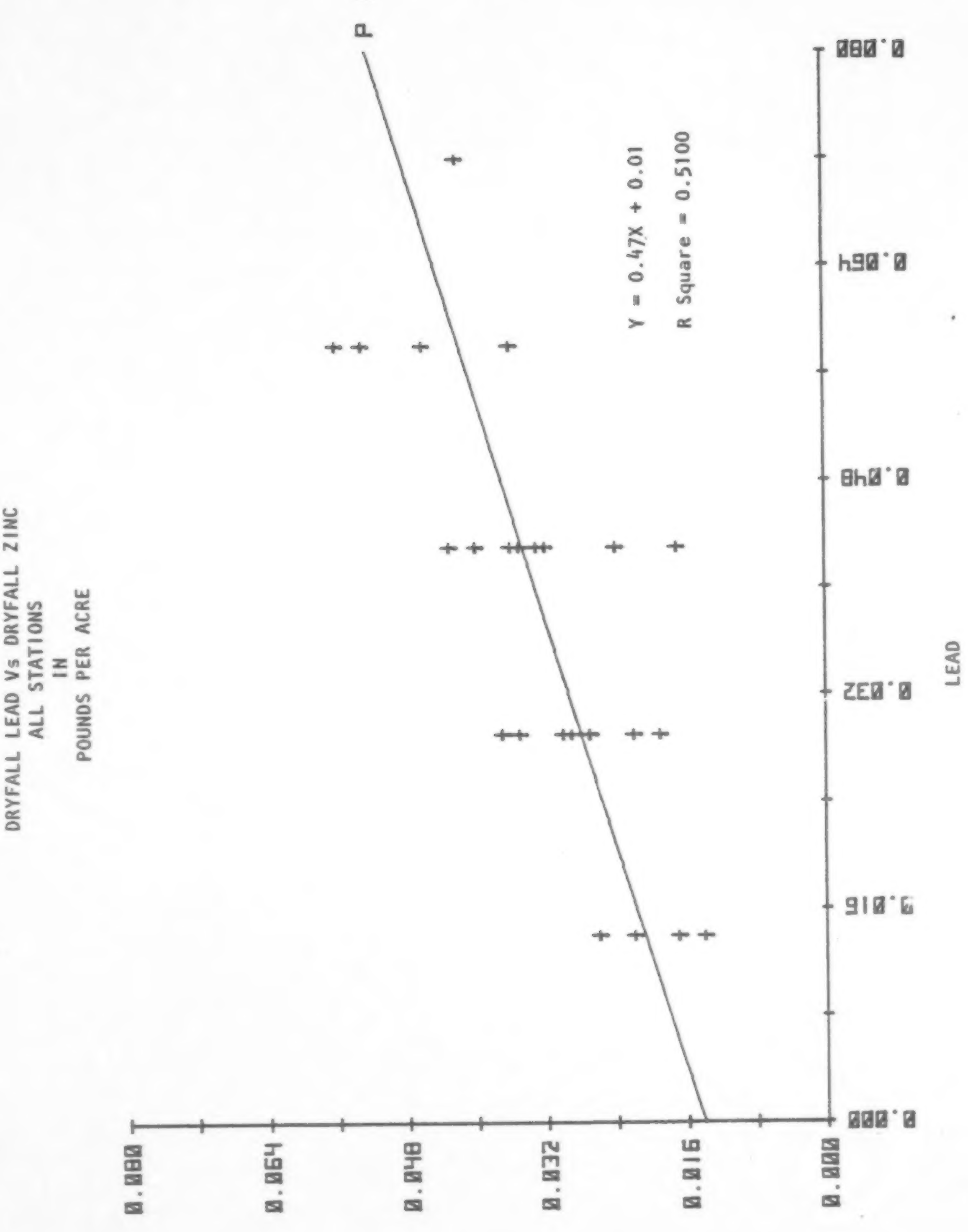

DRYFALL LEAD Vs DRYFALL ZINC
ALL STATIONS
IN
POUNDS PER ACRE
Y = 0.47X + 0.01
R Square = 0.5100
P I
ZINC
0.000
0.016
0.032
0.048
0.064
0.080
LEAD
0.000
0.016
0.032
0.048
0.064
0.080

Figure 29

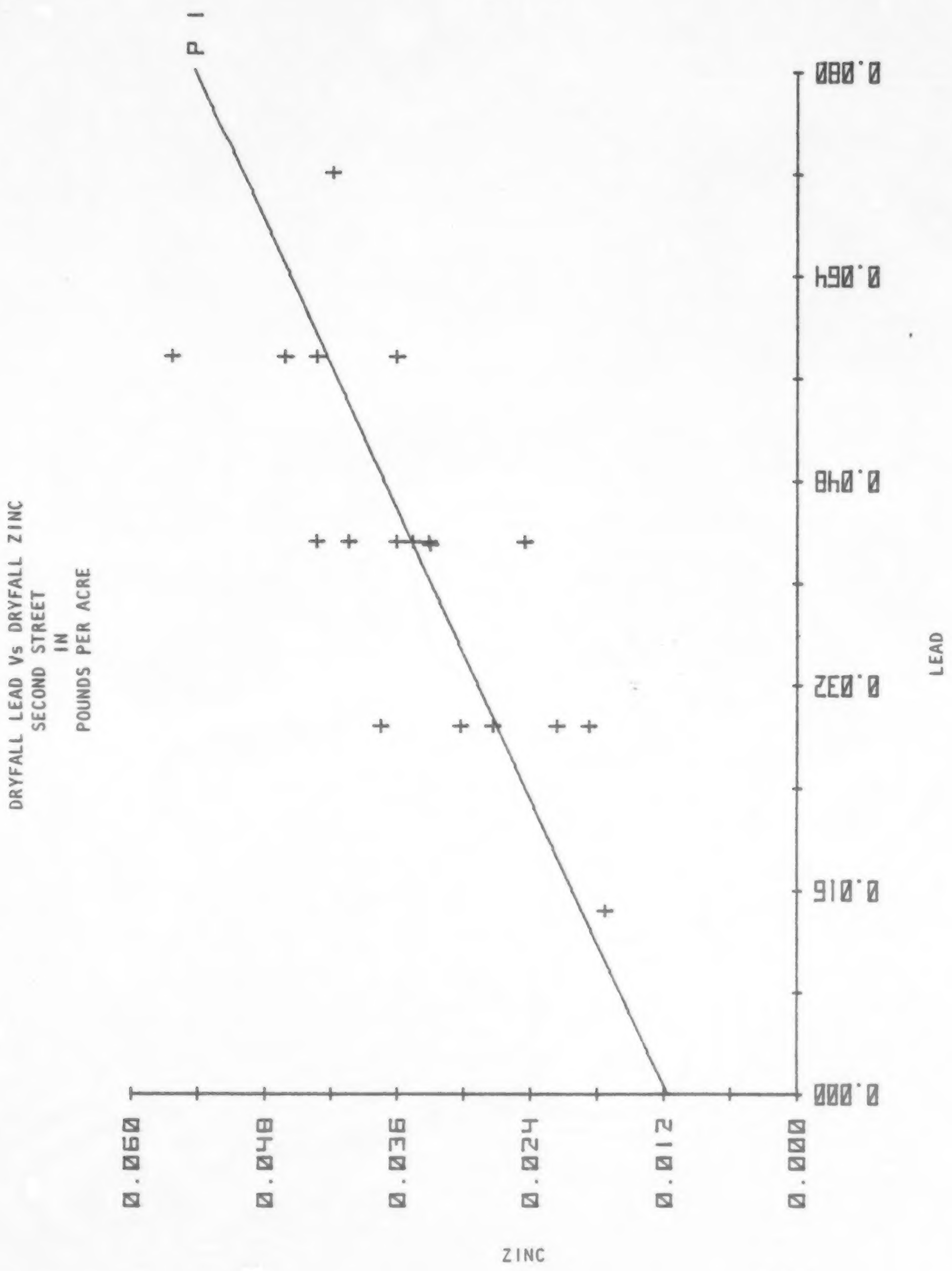

DRYFALL LEAD Vs DRYFALL ZINC
SECOND STREET
IN
POUNDS PER ACRE
P I
LEAD
0.000
0.016
0.032
0.048
0.064
0.080
ZINC
0.000
0.012
0.024
0.036
0.048
0.060

Figure 30

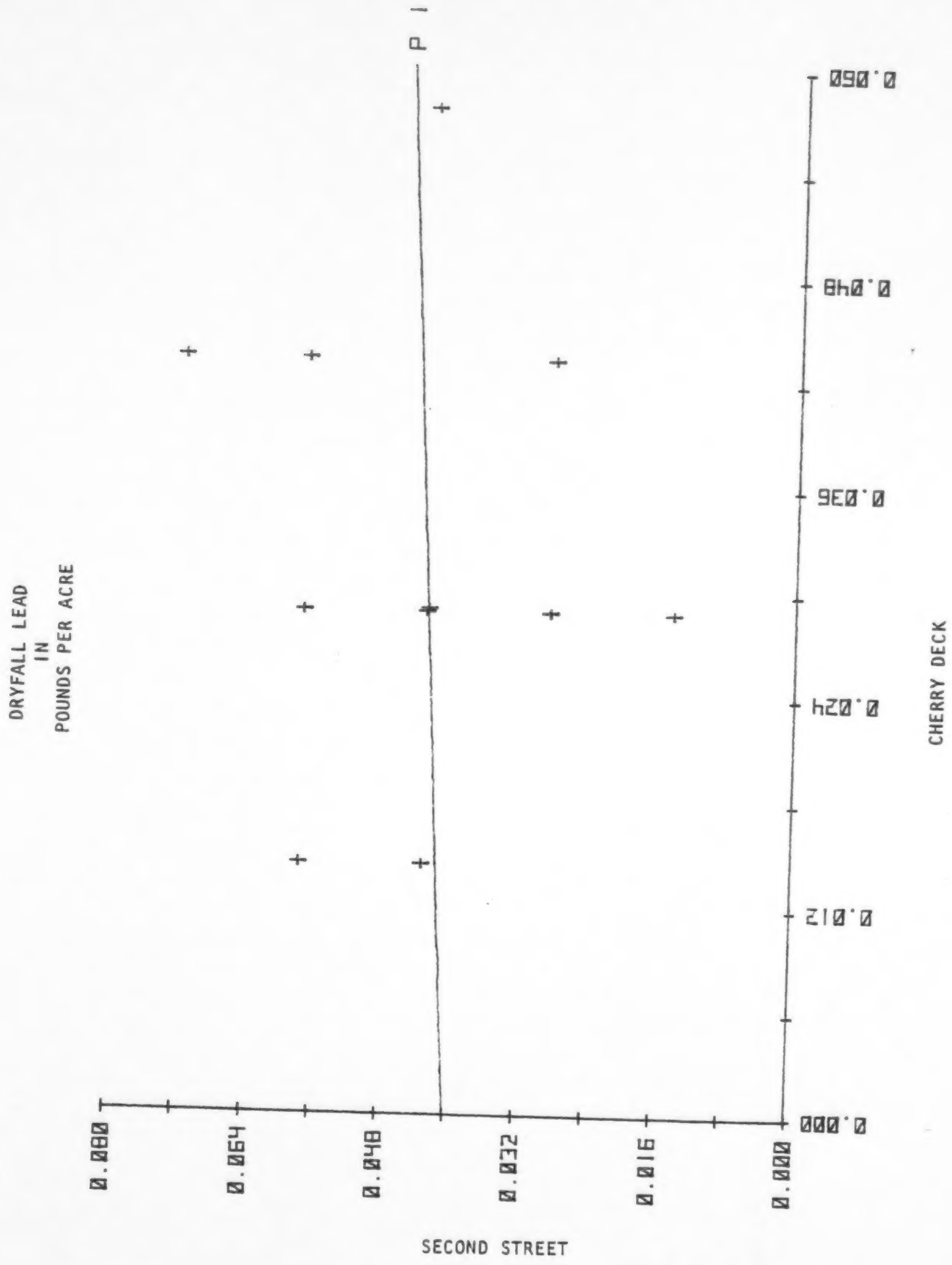

P 1
DRYFALL LEAD
IN
POUNDS PER ACRE
CHERRY DECK
SECOND STREET
0.000
0.012
0.024
0.036
0.048
0.060
0.000
0.016
0.032
0.048
0.064
0.080

Figure 31

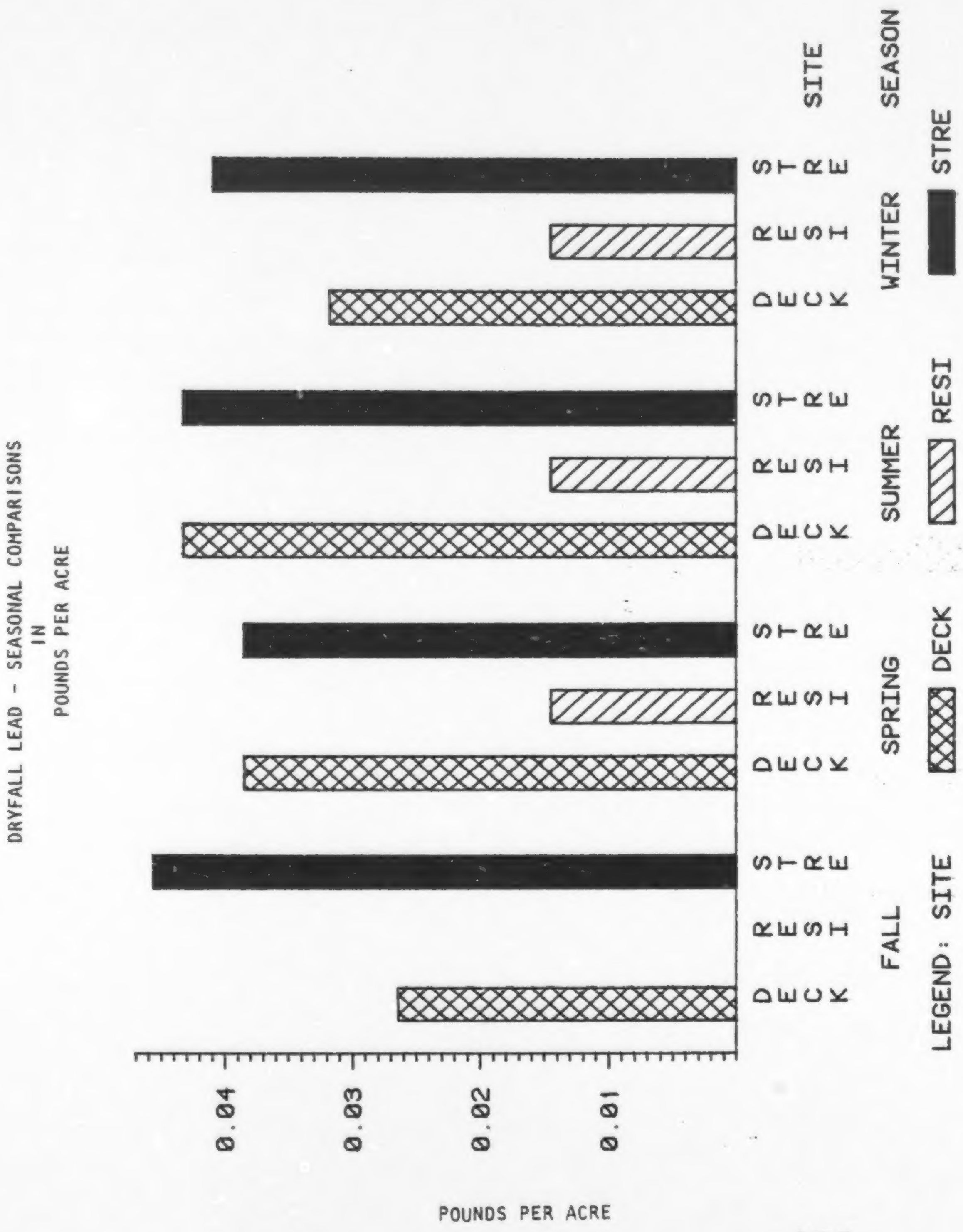

DRYFALL LEAD - SEASONAL COMPARISONS IN POUNDS PER ACRE

Figure 32

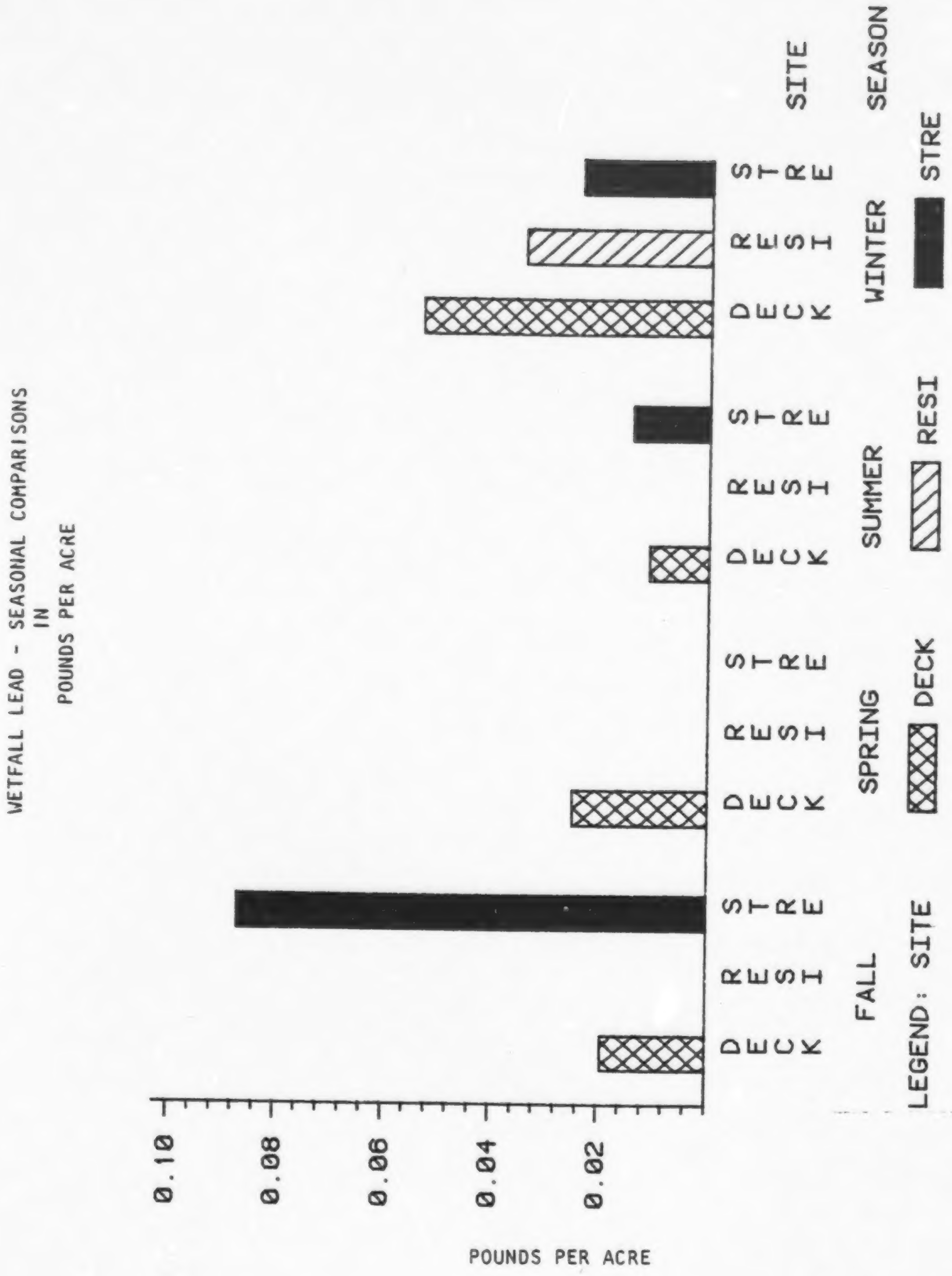

WETFALL LEAD - SEASONAL COMPARISONS
IN
POUNDS PER ACRE
POUNDS PER ACRE
0.10
0.08
0.06
0.04
0.02
DECK
RESI
STRE
FALL
SPRING
SUMMER
WINTER
SITE
SEASON
LEGEND: SITE
DECK
RESI
STRE

Figure 33

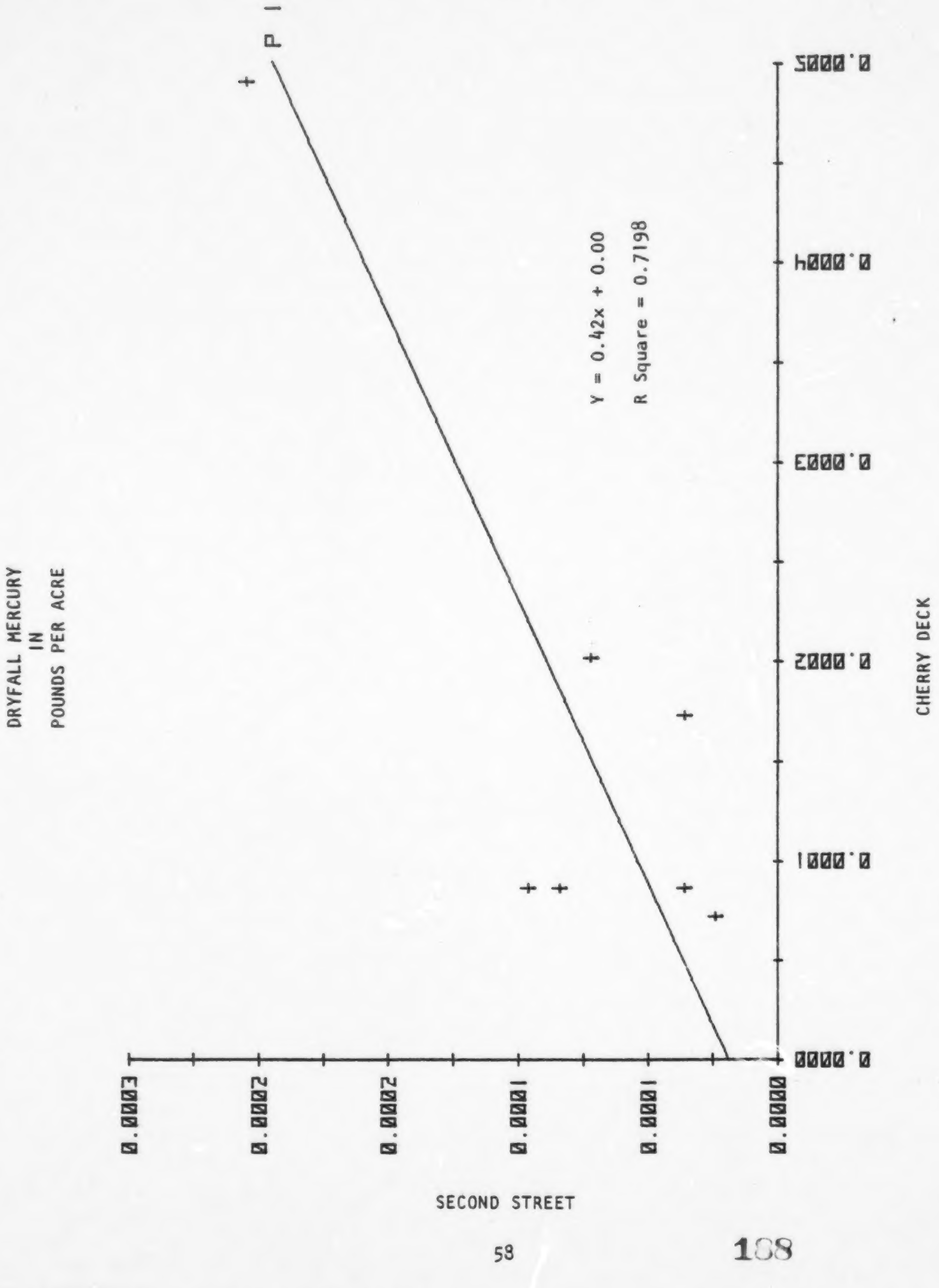

DRYFALL MERCURY
IN
POUNDS PER ACRE
P I
Y = 0.42x + 0.00
R Square = 0.7198
0.0003
0.0002
0.0002
0.0001
0.0001
0.0000
0.0000
0.0001
0.0002
0.0003
0.0004
0.0005
CHERRY DECK
SECOND STREET

Figure 34

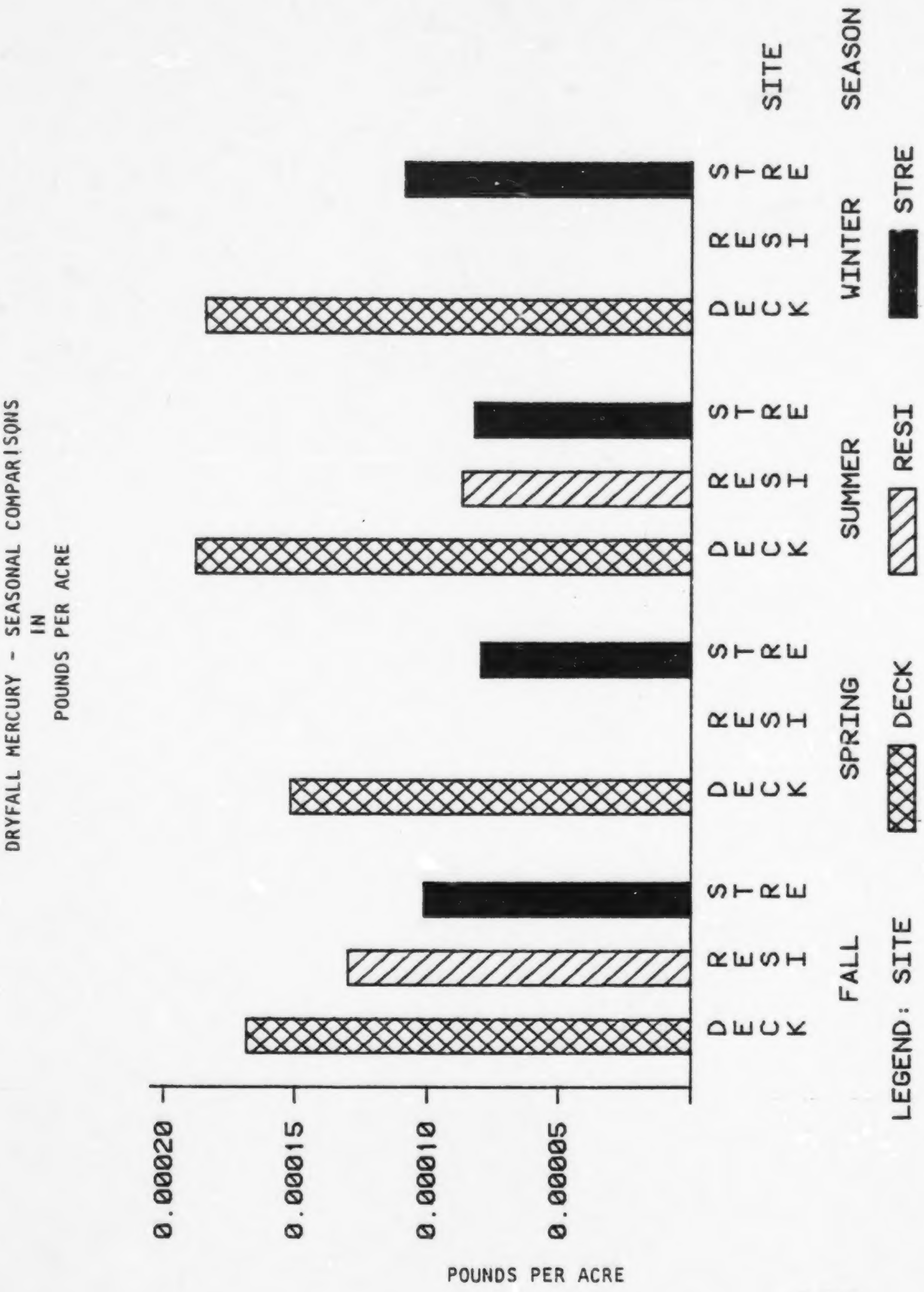
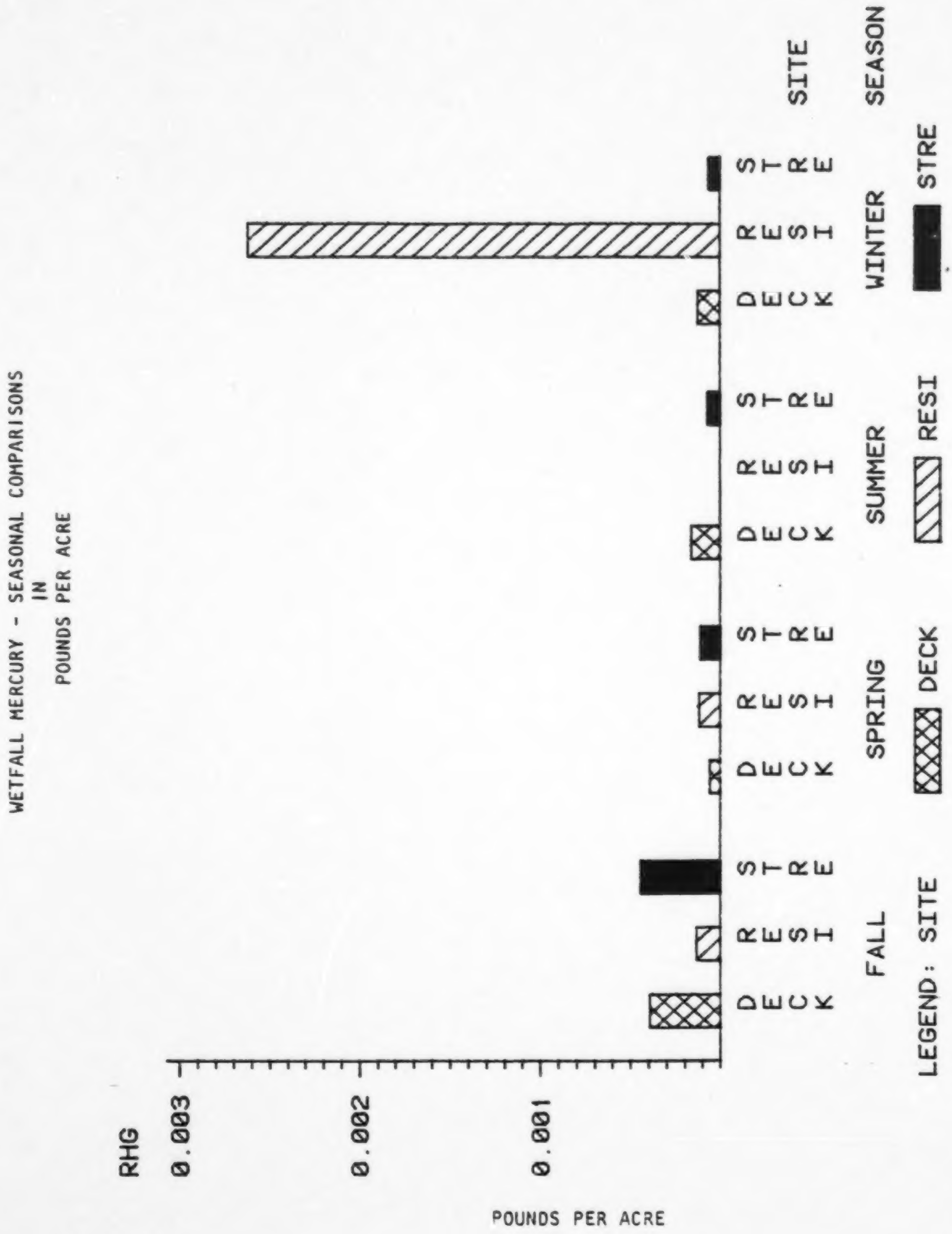

DRYFALL MERCURY - SEASONAL COMPARISONS
IN
POUNDS PER ACRE
POUNDS PER ACRE
0.00020
0.00015
0.00010
0.00005
DECK
RESI
STRE
FALL
SPRING
SUMMER
WINTER
SITE
SEASON
LEGEND: SITE
DECK
RESI
STRE

Figure 35


WETFALL MERCURY - SEASONAL COMPARISONS
IN
POUNDS PER ACRE
RHG
0.003
0.002
0.001
POUNDS PER ACRE
DECK
RESI
STRE
FALL
SPRING
SUMMER
WINTER
SITE
SEASON
LEGEND: SITE
DECK
RESI
STRE

ATMOSPHERIC DEPOSITION ANALYSIS - RELATED PARAMETERS

Total Composite Samples

General:

The weights of each of the eight measured pollutants were added to determine a total composite weight for each sample, both wet and dry.

Data analysis:

No significant differences in total composite pollutant deposition were determined from either the wetfall or dryfall data comparisons at the Cherry Deck and the Second Street sites. The Residential watershed comparisons, however, indicated a higher pollutant content in wetfall samples than in dryfall ($t_{.05[9]} = 2.73$). Interwatershed comparisons indicated no appreciable differences in either wetfall or dryfall total pollutant weights. In fact, linear correlation analyses of wetfall pollutant loads were significant at the .001 level for both the Cherry Deck to Second Street and the Cherry Deck to RES comparisons ($r^2_{[19]} = .8917$; and $r^2_{[12]} = .8677$, respectively). Figures 36 and 37 show the graphs of these analyses. Correlations of dryfall amounts were less significant, with the data displaying more variability than in the wetfall, Figures 38 and 39.

The total amount of wetfall at each station was measured for each event and expressed as inches of rain. All stations were comparable in total amounts, indicating that individual pollutant differences were probably not a result of variation in total wetfall volumes. Figures 40 and 41 graphically display the data from the linear correlation analyses of these station wetfall totals. Both interactions are significant at the .001 level, with the Deck to Street having a $r^2_{[55]} = .9771$, and the Deck to RES having a $r^2_{[28]} = .9753$.

The differences in amount of wetfall and dryfall total composites may be a function of consistent (or inconsistent) appearance of particular pollutants in the deposition. Wetfall TKN amounts, for example, contribute a constant amount to the total composite weight (Figure 42), while metals are rarely detected and vary widely in amount. No constant contributor to dryfall composites was determined.

Seasonal distributions of total composited weights for wetfall and dryfall seem to indicate a greater abundance of pollutants in the CBD than in the Residential watershed in every part of the year. A statistical significance of this difference was not found, perhaps because of the relatively low number of samples collected at the RES site. The Second Street monitor appeared to be more heavily loaded than either the Cherry Deck or the Residential monitors (Figures 43 and 44).

PH Analysis

General:

The pH of a solution is expressed as the logarithm of the reciprocal of the hydrogen ion activity in moles per liter at a given temperature. The practical scale extends from 0 (very acidic) to 14 (very alkaline), with 7 corresponding to exact neutrality at 25°C. Whereas alkalinity and acidity are measures of total resistance to pH change or buffering capacity of a sample, pH represents the free hydrogen ion activity not bound by carbonate or other bases. The pH of most natural waters falls in the range of 4 to 9, with the majority being slightly basic. Changes in the normal pH for a given water may indicate the discharge of alkaline or acidic wastes (Shelley, 1979).

Data analysis:

PH values were determined for all wetfall events monitored at the three deposition stations, with data from the Cherry Deck and the Second Street stations beginning in August of 1980, and that from the Residential station beginning in May of 1981. During the study period, sixty-seven rainfall events were analyzed from both the Cherry Deck and Second Street collectors, while only thirty-six events were analyzed from the abbreviated monitoring at the RES station.

As would be expected from reports of numerous other studies involving east coast acid precipitation (Cogbill and Likins, 1974; Glass, et al, 1978; Galloway and Cowling, 1978; Babich, et al 1980), mean pH values established at all three Winston-Salem monitoring stations were below the 5.6 level indicative of "pure" rainfall. A mean pH of 3.82 was establised independently from each of the two CBD collectors (Cherry Deck and Second Street) for the sixty-seven rain events monitored. The mean of the thirty-six analyzed RES events was calculated to be essentially the same at pH 3.75. When the CBD watershed and the RES watershed were compared within the same time period (beginning in May of 1981), the mean pH from the CBD events was 3.74, comparable to the RES pH of 3.75. PH values were recorded as a function of their negative hydrogen ion concentrations and then averaged prior to converting them into pH units (Table 4).

Statistical comparisons were undertaken to determine either a difference between the two watersheds, or a difference between the monitoring locations within the CBD watershed (street level on Second Street vs. the four story Cherry Parking Deck). Paired t-analyses of the pH data from the two watersheds indicated no significant difference between their levels ($t_{.2[ss]} = 1.5169$), nor was a significant difference calculated from the data collected at the two CBD monitoring stations ($t_{.2[28]} = 1.3059$).

A linear correlation of the data from the two watersheds indicated a highly significant linear trend ($r^2_{.001[28]} = .7505$, Figure 45). Correlation of the data from the two CBD stations, likewise, indicated a strong linearity ($r^2_{.001[55]} = .8867$, Figure 46). These trends are indicative of the fact that pH fluctuations, during the time frame of the project, were essentially the same city wide.

It was felt that a large volume rain event having a low pH would be more detrimental to the watershed than a small volume rain event having the same low pH. In order to quantify the relative impact of these volume related differences a second method of handling and intercomparing pH data was conducted on the basis of "rainfall amount pH weighting". These values were calculated by multiplying the hydrogen ion concentrations per event by the rainfall amounts per event, summing the products and dividing the resulting sum by the sum of the individual rainfall amounts. This "weighted" ion concentration was then converted into pH units. The weighted average for the Second Street site was calculated to be 3.82; the Deck, 3.83; and the RES, 3.82. These "weighted means" are not significantly different from the "unweighted means" calculated for the three stations, which indicates that the fluctuations in rainfall amount did not introduce an unseen bias in the overall pH levels calculated for the two monitored watersheds.

A linear correlation of wetfall sulfate levels and pH data indicated no interaction between these two parameters. It should be noted, however, that sulfate analyses were initiated late in the project, and therefore, only a few events were available for this comparison (seven events for the Cherry Deck, six for the Second Street, and eleven for the RES). Given the limited data set, it is impossible to rule out the possibility that sulfates play a role in the lowering of rainfall pH levels in this area.

Total Suspended Particulates (TSP)

One high volume air sampler was operated throughout the project at the Cherry Deck site. Samples were collected once every six days beginning in June, 1980. The geometric mean concentration for the period beginning with the first sample, and ending one year later was 66 micrograms per cubic meter (ug/m^3). The mean for the following year was 63 ug/m^3. Sixteen filters, of the 121 collected during the project were selected for further study. They were chosen to represent all seasons, a variety of weather conditions, all days of the week and a wide range of TSP concentrations.

Complete analysis of these filters indicated that traffic on unpaved and paved surfaces appeared to be the primary contributor of particles to the TSP concentrations. Particles emitted directly from vehicles, and minerals suspended by traffic, contributed at least 36% of the particulate matter, with an average of 51% contribution. Abraded pavement was ruled out as a source of any more than 10 to 20 percent of the mineral fraction, suggesting that traffic on unpaved surfaces or heavily soiled paved surfaces provided the greatest impact. Large particle sizes suggested that the emission sources of the mineral materials were located within a few hundred feet of the sampling site.

There appeared, likewise, to be a relationship between mineral content and seasons of the year. Mineral concentrations were higher during warmer (and dryer) months ($\bar{x}$ =45.25 mass %) than during colder (and moister) times of the year ($\bar{x}$ =36.00 mass %). Rubber tire fragment concentrations were fairly constant in all samples, even though mineral concentrations fluctuated by as much as 100%. This "suggests the possibility that the dust burden on paved surfaces is an important factor in traffic contributions to TSP. That is, accumulated, resuspended minerals deposited on paved roadways, from unpaved surfaces, may well contribute as much to the TSP as do the direct emissions from unpaved parking lots," (Graf, 1981).

Wind roses were constructed from directional data gathered in the six hours immediately preceding a storm event. Figures 47 and 48 illustrate the similarity in the two watersheds in winds preceding a storm. Overall annual winds, excluding days having storm events, were similar to those which have been observed during the past ten years, Figure 49.

Correlations of individual pollutant concentrations to wind speeds and direction were unavailable at the time this report was written. They will be added as an addendum to the report by NRCD-DEM personnel as soon as possible.

Figure 36

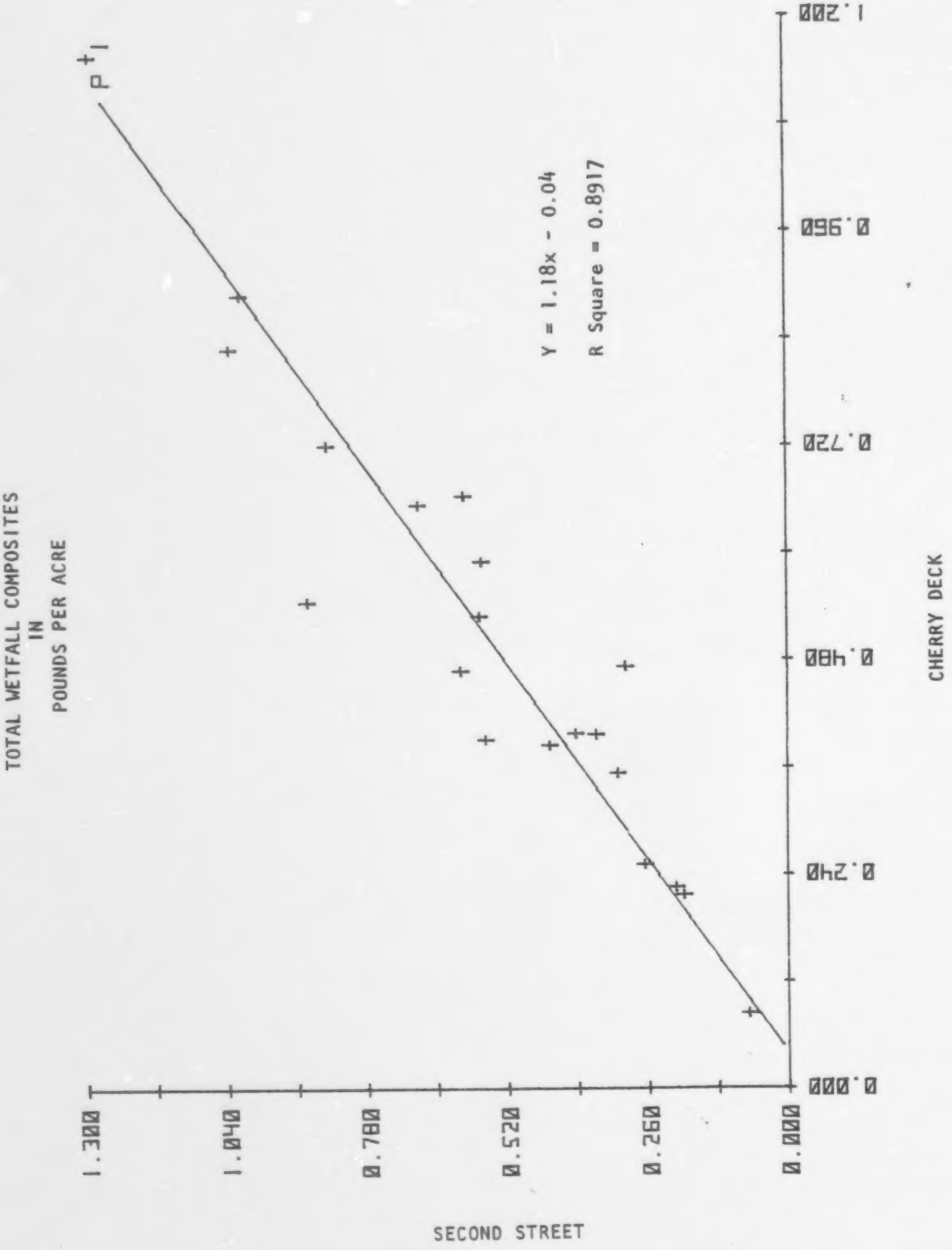

TOTAL WETFALL COMPOSITES
IN
POUNDS PER ACRE
Y = 1.18x - 0.04
R Square = 0.8917
P
I
1.300
1.040
0.780
0.520
0.260
0.000
0.000
0.240
0.480
0.720
0.960
1.200
CHERRY DECK
SECOND STREET

Figure 37

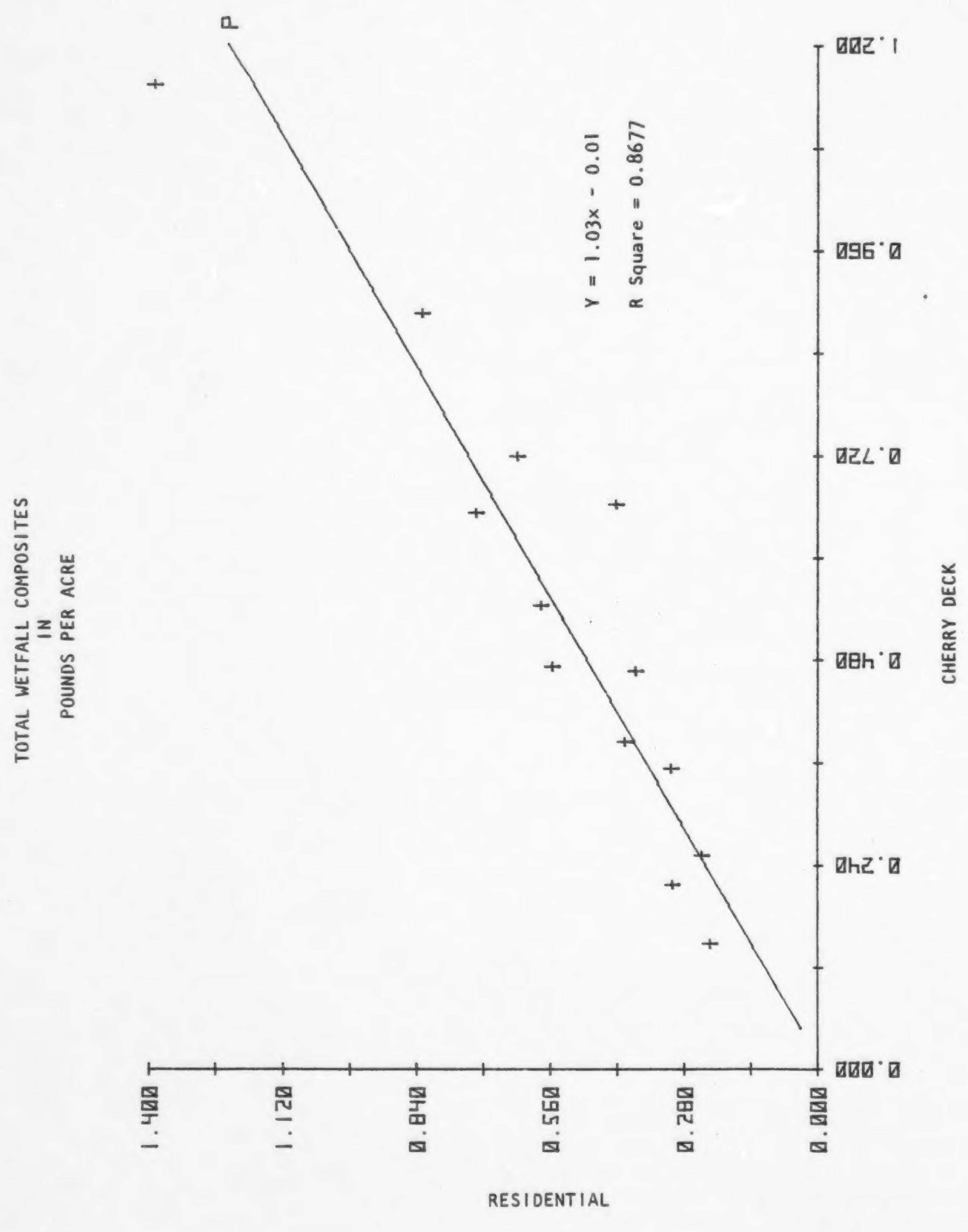

TOTAL WETFALL COMPOSITES
IN
POUNDS PER ACRE
P I
Y = 1.03x - 0.01
R Square = 0.8677
CHERRY DECK
0.000
0.240
0.480
0.720
0.960
1.200
RESIDENTIAL
0.000
0.280
0.560
0.840
1.120
1.400

Figure 38

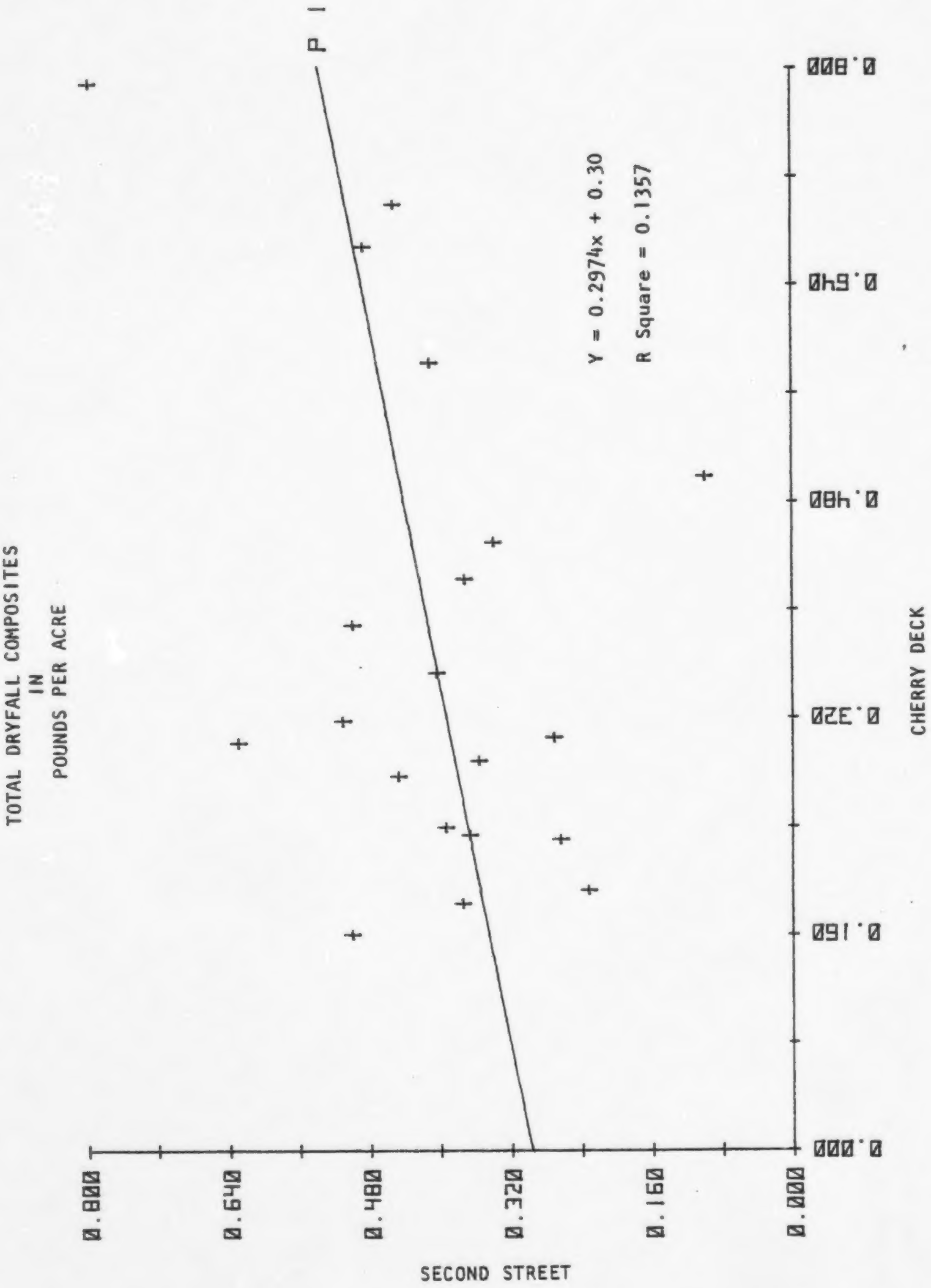
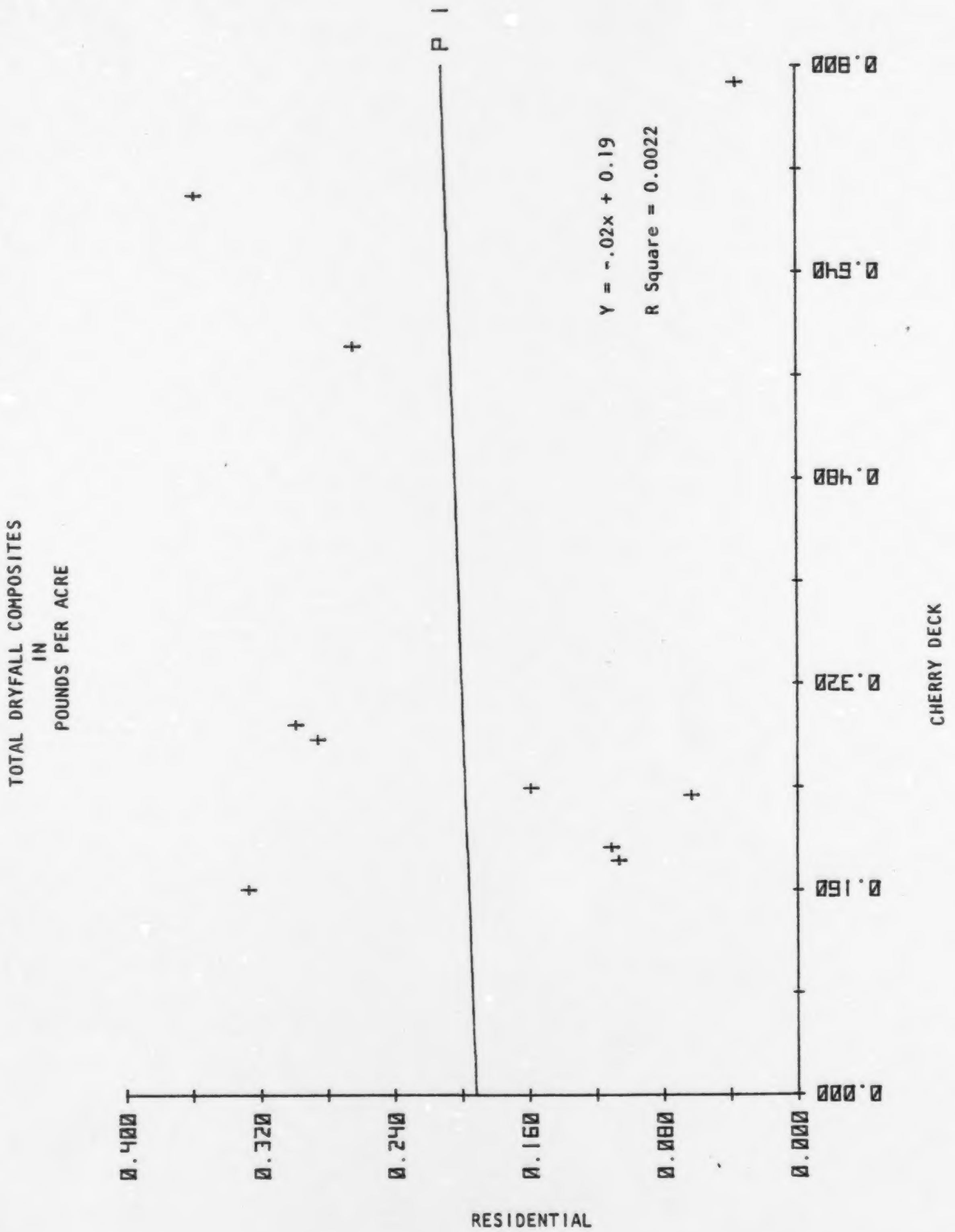
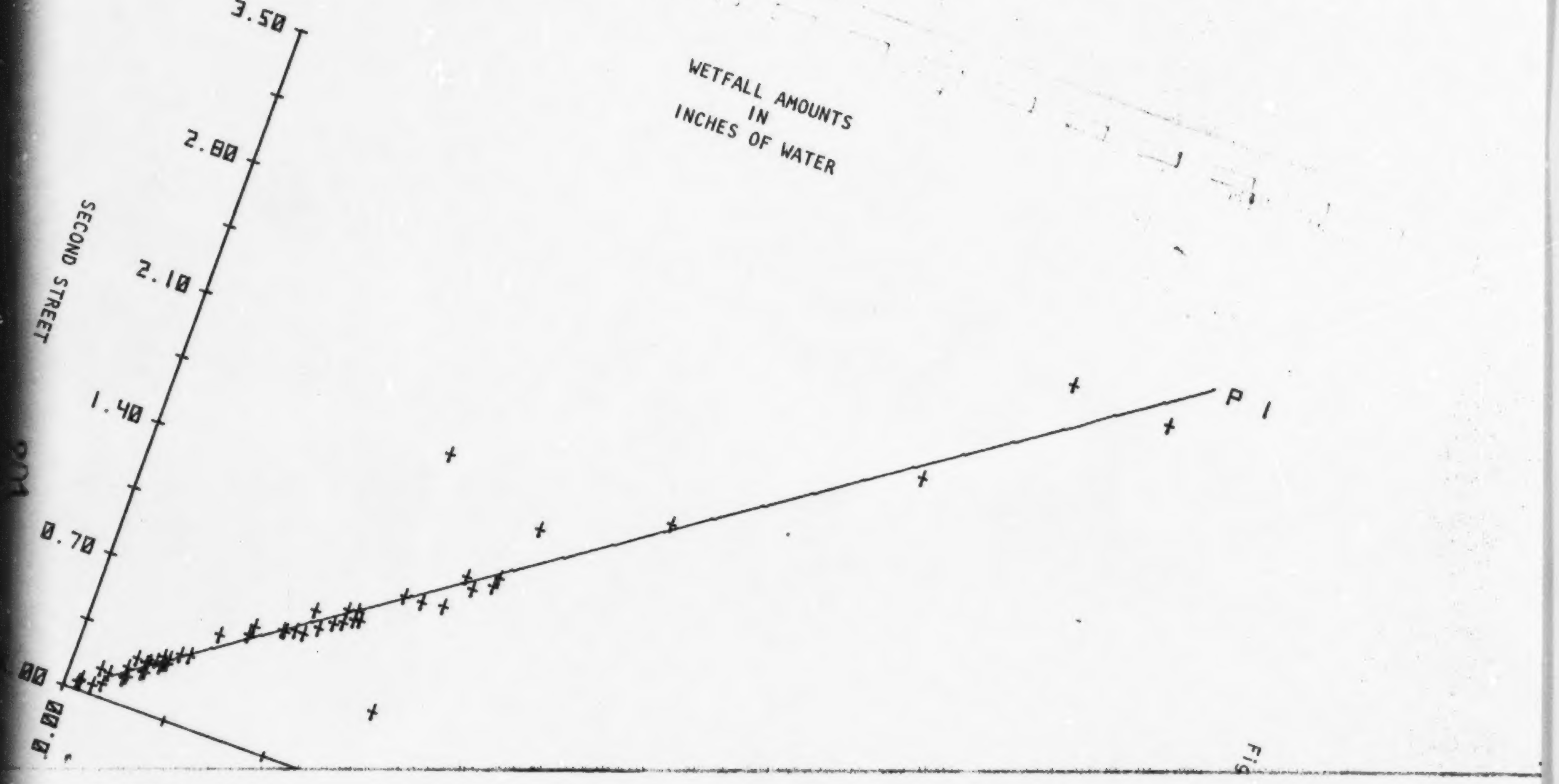

TOTAL DRYFALL COMPOSITES
IN
POUNDS PER ACRE
Y = 0.2974x + 0.30
R Square = 0.1357
P I
0.000
0.160
0.320
0.480
0.640
0.800
CHERRY DECK
0.000
0.160
0.320
0.480
0.640
0.800
SECOND STREET

Figure 39


TOTAL DRYFALL COMPOSITES
IN
POUNDS PER ACRE
P I
Y = -.02x + 0.19
R Square = 0.0022
0.400
0.320
0.240
0.160
0.080
0.000
RESIDENTIAL
0.000
0.160
0.320
0.480
0.640
0.800
CHERRY DECK


WETFALL AMOUNTS
IN
INCHES OF WATER
SECOND STREET
3.50
2.80
2.10
1.40
0.70
0.00
0.00
P I

Fig

Figure 41

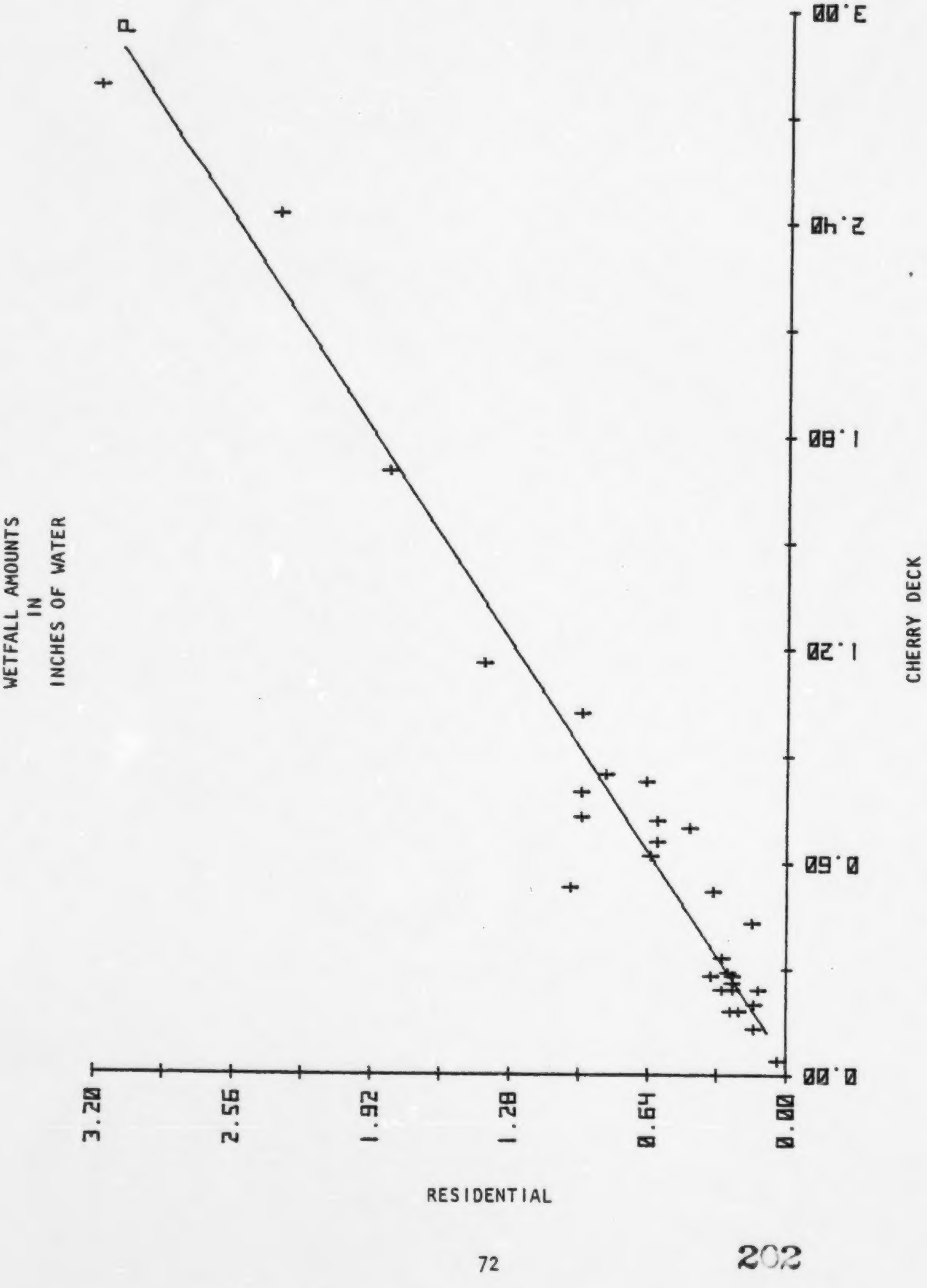

WETFALL AMOUNTS
IN
INCHES OF WATER
P I
3.20
2.56
1.92
1.28
0.64
0.00
RESIDENTIAL
0.00
0.60
1.20
1.80
2.40
3.00
CHERRY DECK

Figure 42

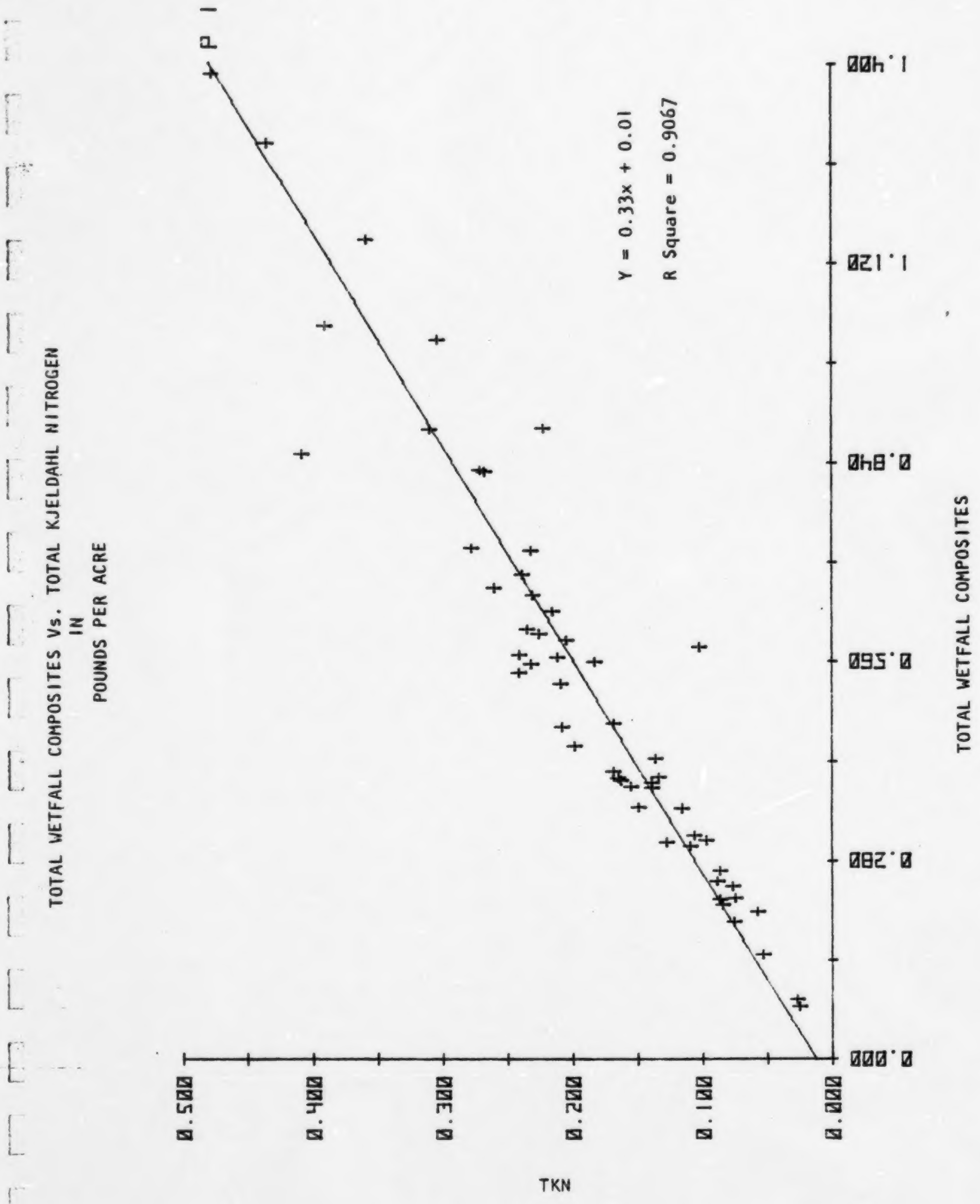
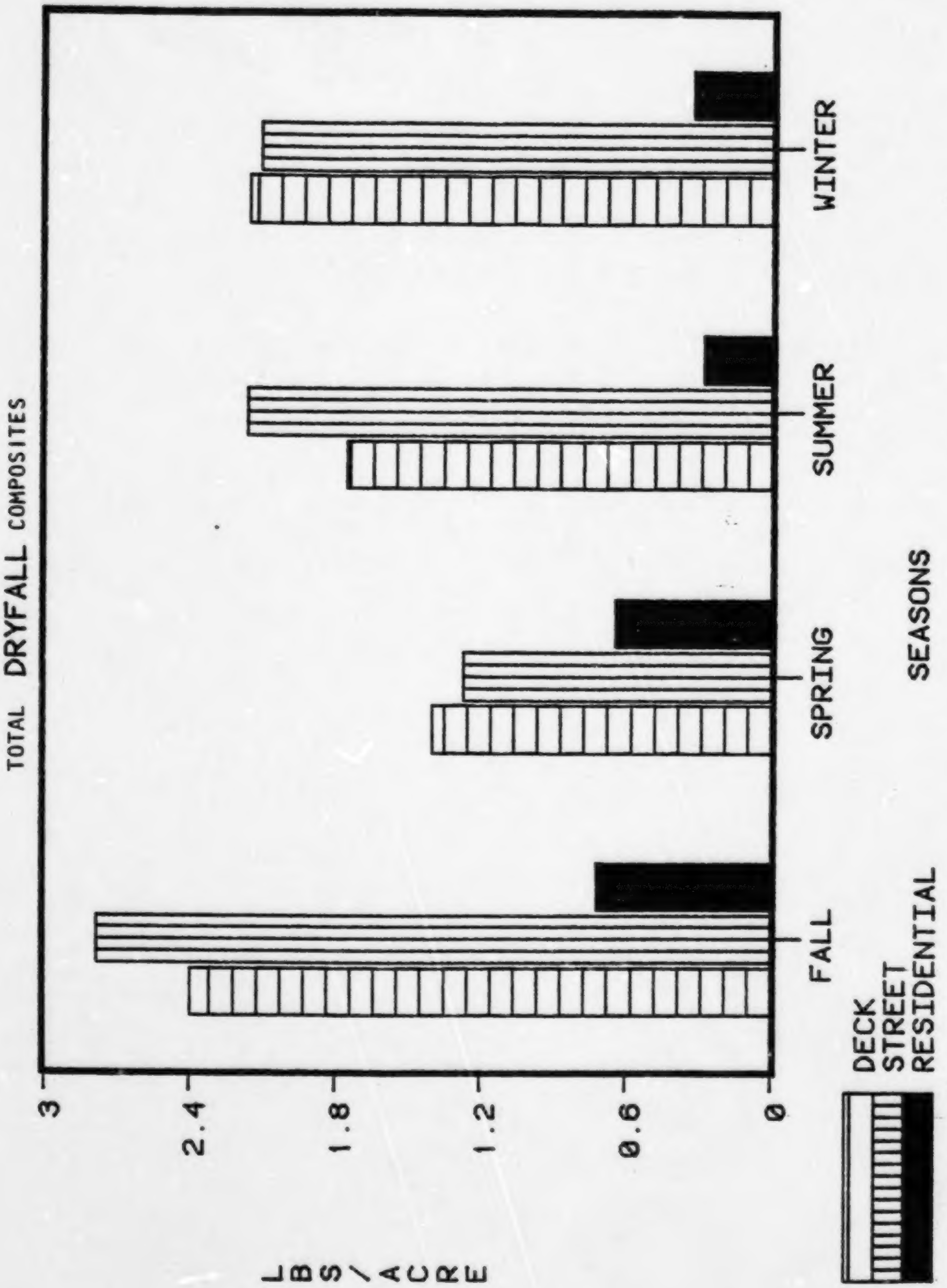

TOTAL WETFALL COMPOSITES Vs. TOTAL KJELDAHL NITROGEN
IN
POUNDS PER ACRE
Y = 0.33x + 0.01
R Square = 0.9067
P I
TKN
0.000
0.100
0.200
0.300
0.400
0.500
TOTAL WETFALL COMPOSITES
0.000
0.280
0.560
0.840
1.120
1.400

Figure 43


TOTAL DRYFALL COMPOSITES
LBS/ACRE
3
2.4
1.8
1.2
0.6
0
FALL
SPRING
SUMMER
WINTER
SEASONS
DECK
STREET
RESIDENTIAL

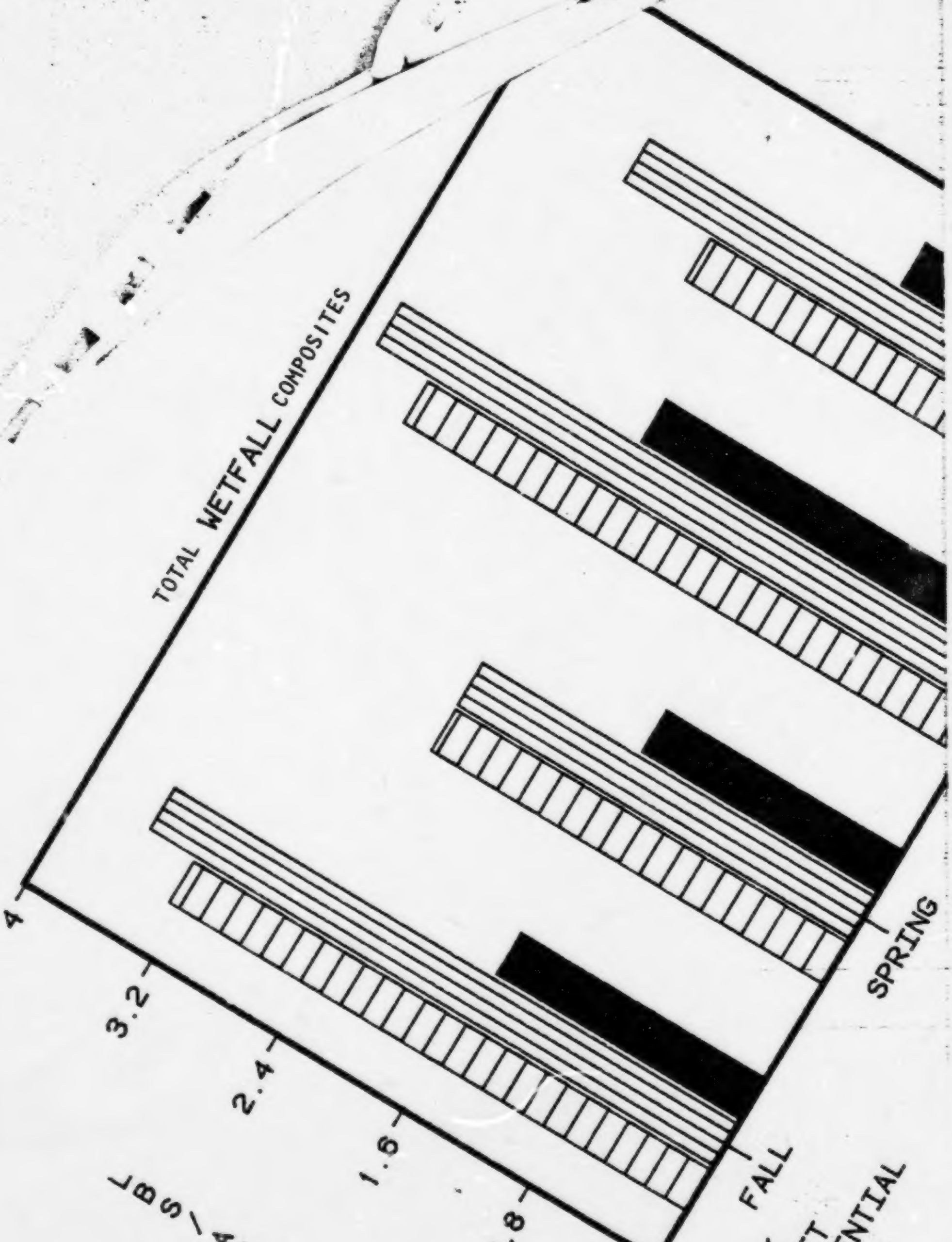

TOTAL WETFALL COMPOSITES
LBS/ACRE
4
3.2
2.4
1.6
0.8
0
FALL
SPRING
DECK
STREET
RESIDENTIAL

Figure 45

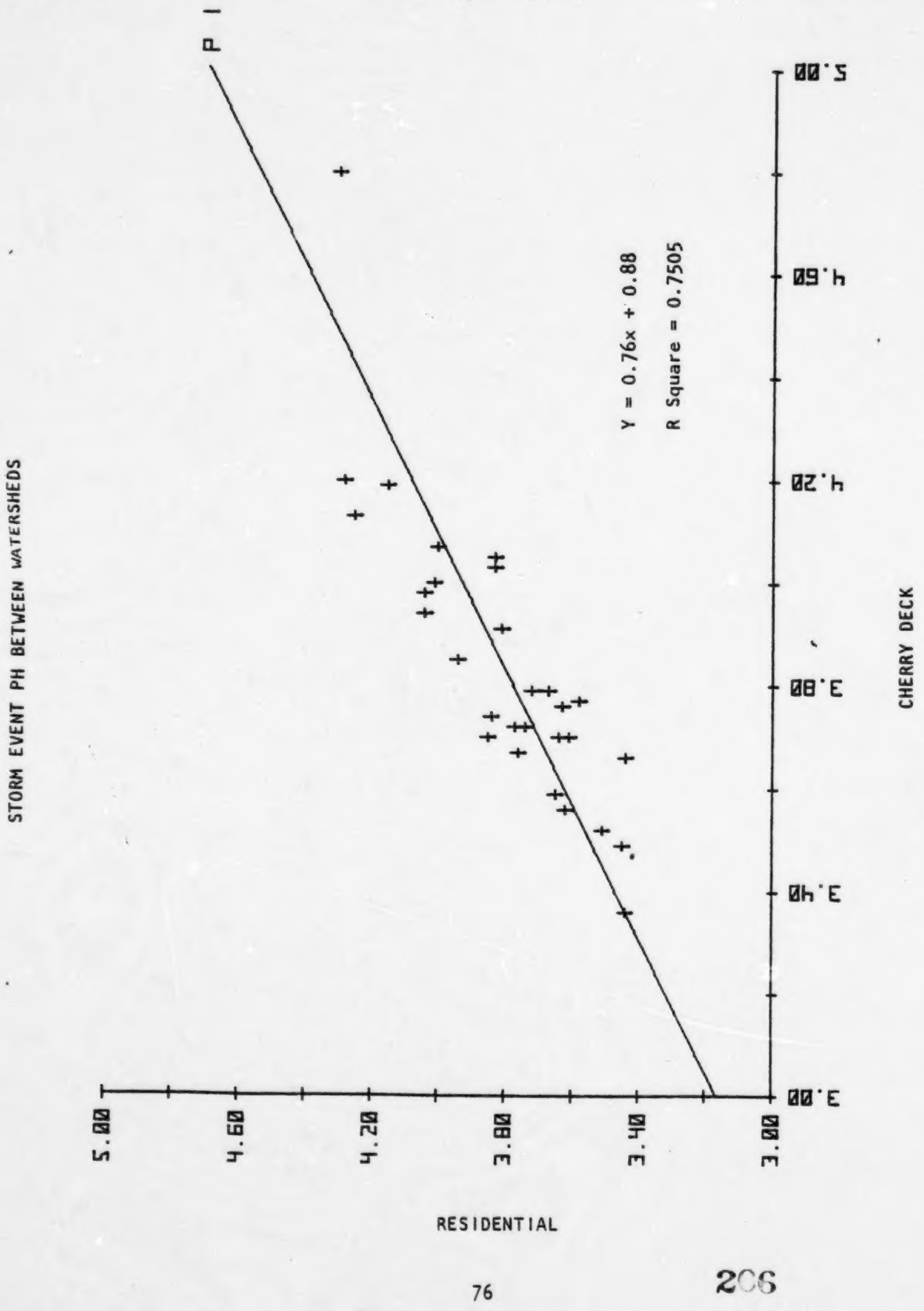

STORM EVENT PH BETWEEN WATERSHEDS
Y = 0.76x + 0.88
R Square = 0.7505
P I
RESIDENTIAL
5.00
4.60
4.20
3.80
3.40
3.00
CHERRY DECK
3.00
3.40
3.80
4.20
4.60
5.00

Figure 46

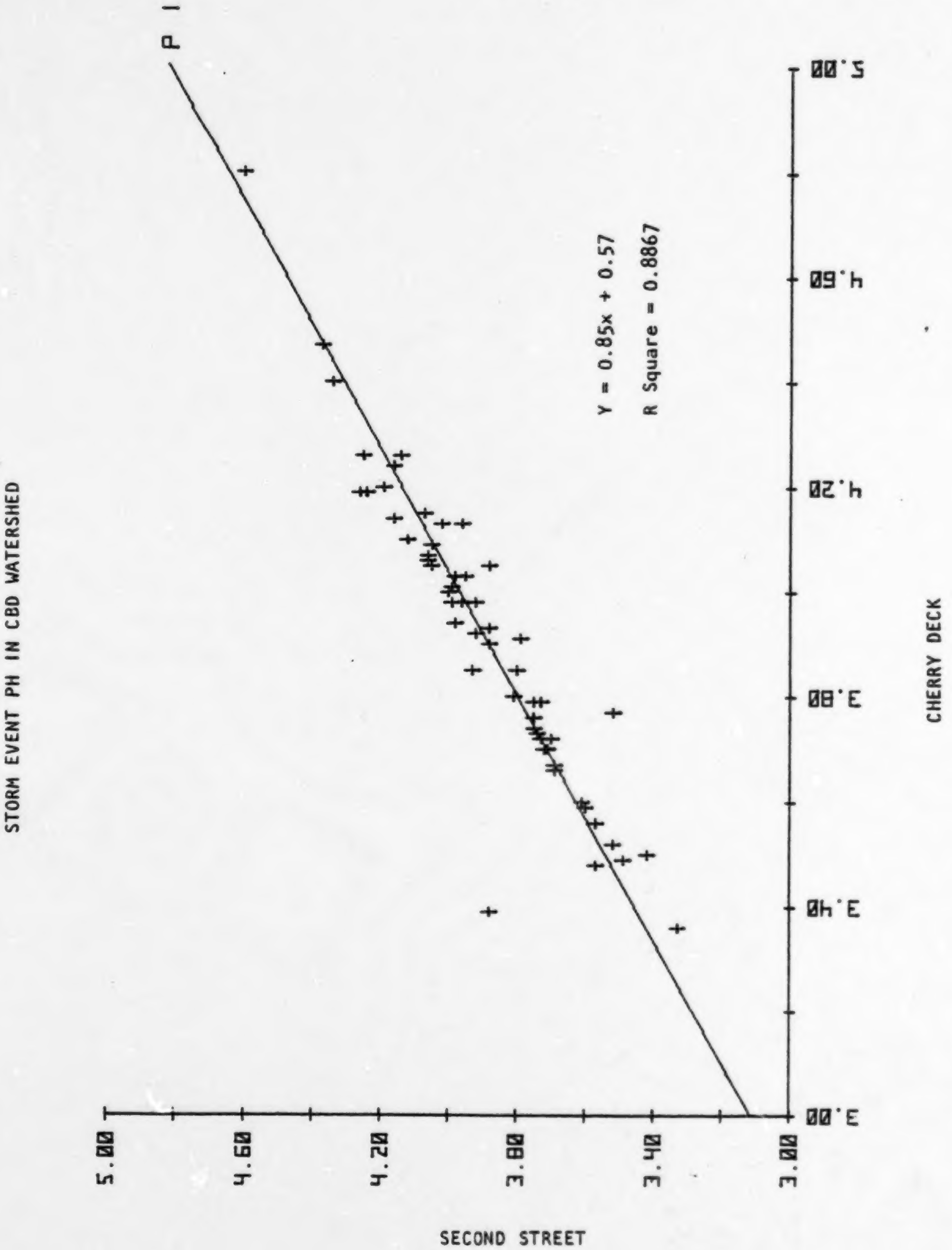

STORM EVENT PH IN CBD WATERSHED

Table 4

RANGES, MEANS AND STANDARD DEVIATIONS OF pH MONITORED AT THE THREE WINSTON-SALEM ATMOSPHERIC DEPOSITION STATIONS

Station	Time Period	Number of Observations	Range of Observations	Mean	Standard Deviation	Weighted Average
Cherry Deck	August 1980	31	3.48-4.47	3.95	0.25	3.92
Second Street	through	31	3.42-4.60	3.92	0.26	3.93
Residential	March 1981	-0-	-	-	-	-
Cherry Deck	April 1981	36	3.36-4.80	3.75	0.25	3.77
Second Street	through	36	3.33-4.35	3.73	0.20	3.76
Residential	December 1981	36	3.44-4.30	3.75	0.23	3.82
Cherry Deck	August 1980	67	3.36-4.80	3.82	0.27	3.82
Second Street	through	67	3.33-4.60	3.82	0.26	3.83
Residential	December 1981	36	3.44-4.30	3.75	0.23	3.82

Figure 47

WIND ROSE--SIX HOURS BEFORE RAIN
ANNUAL RESULTS 1981
CENTRAL BUSINESS DISTRICT

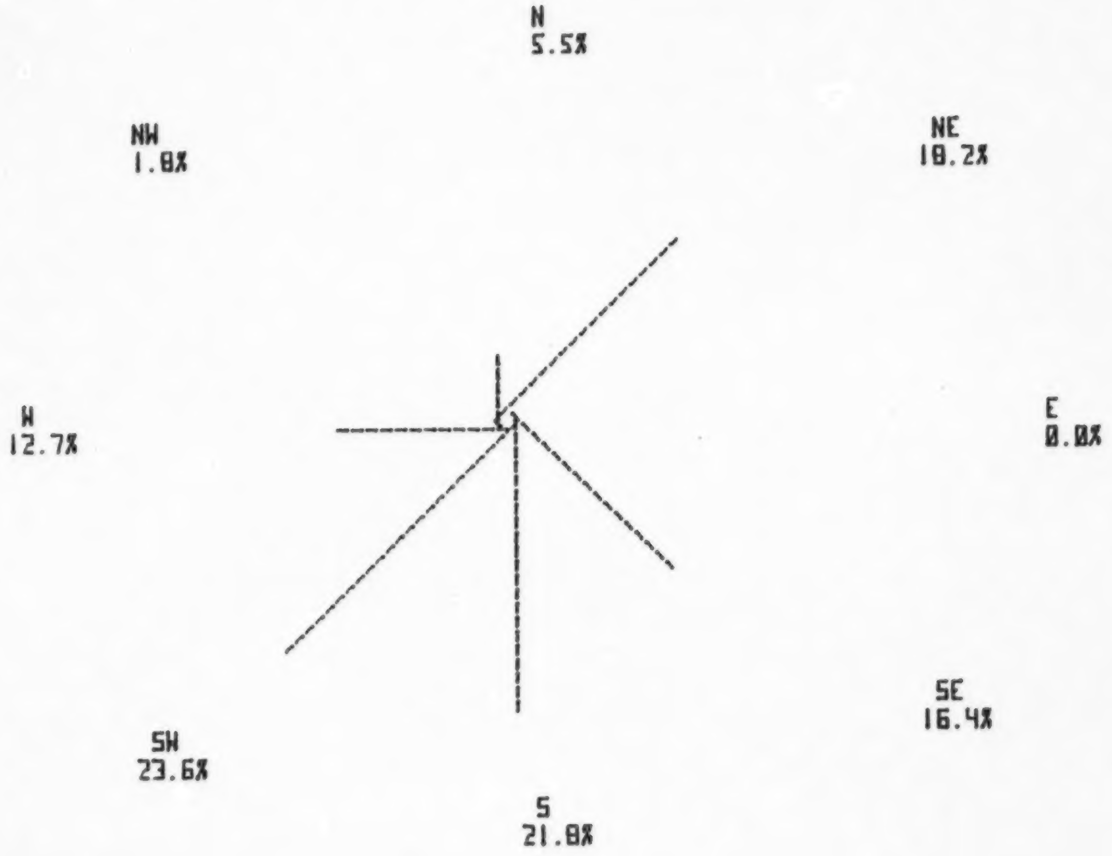


Figure 48

WIND ROSE--SIX HOURS BEFORE RAIN
ANNUAL RESULTS 1981

RESIDENTIAL

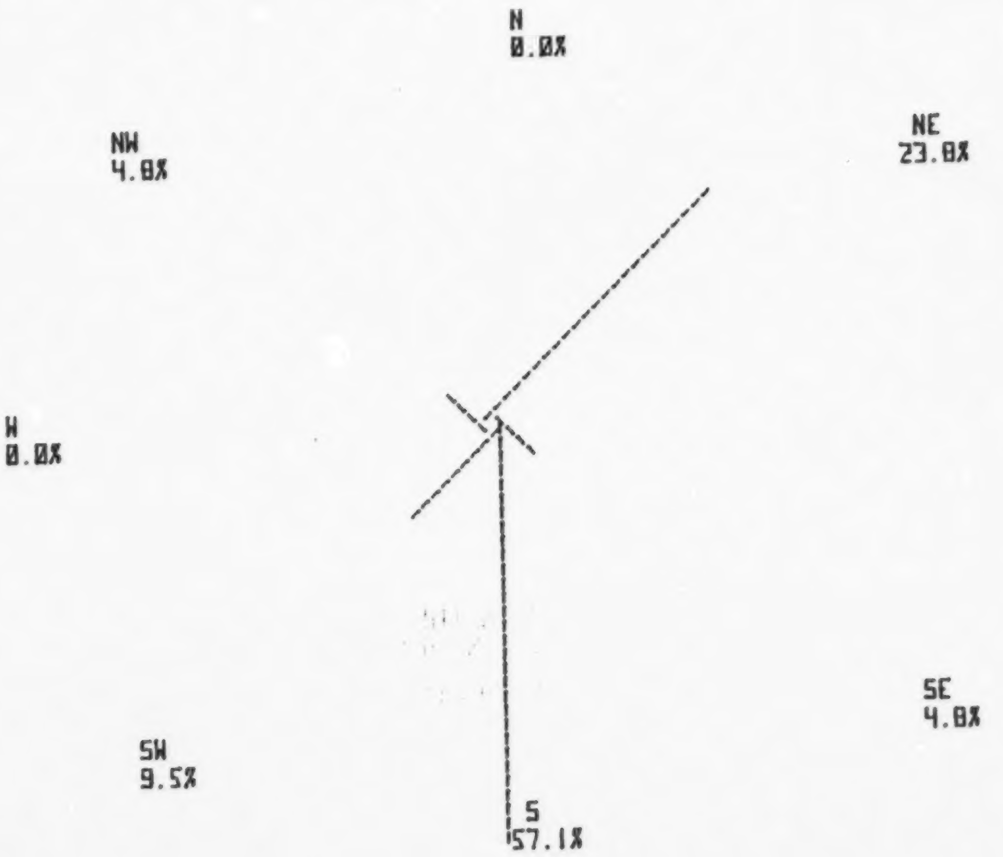
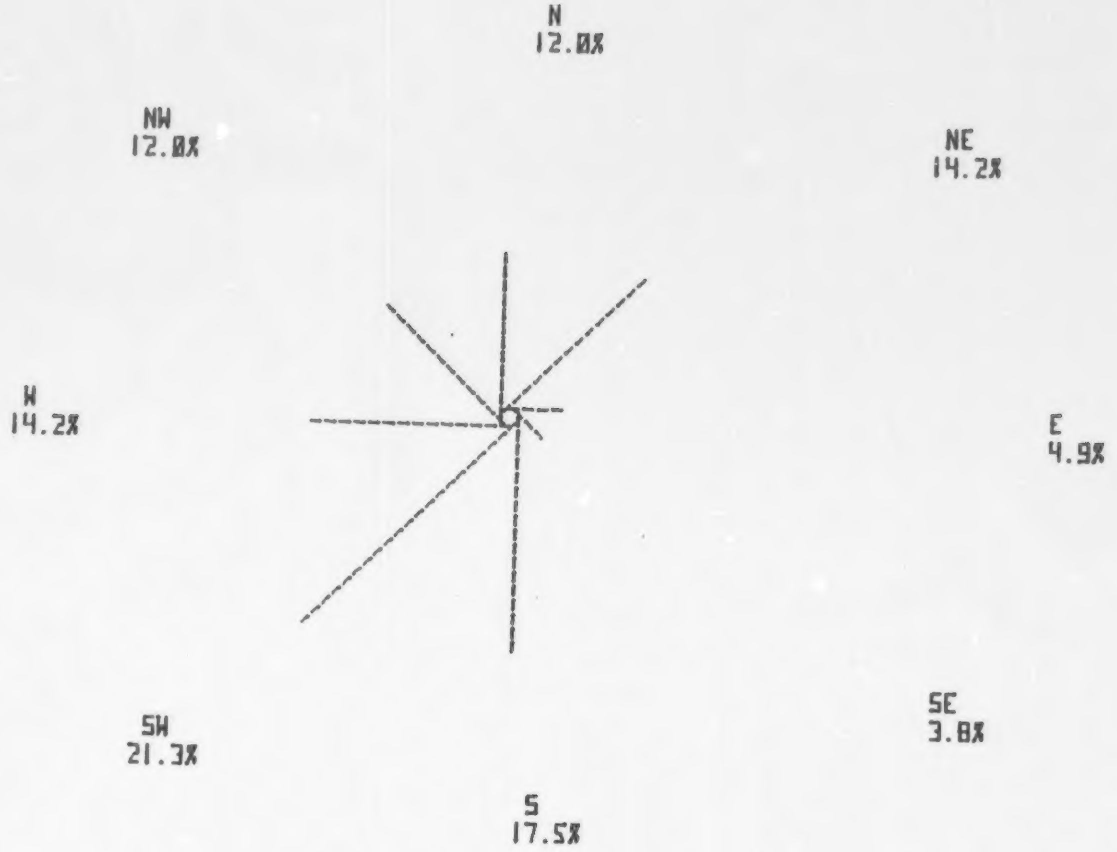


Figure 49

WIND ROSE--RESULTANT DIRECTION
ANNUAL RESULTS 1981

ALL STATIONS



SUMMARY OF RESULTS

As part of the Winston-Salem/Forsyth County Urban Runoff Project, the Environmental Affairs Department operated atmospheric deposition monitoring stations in two different, local watersheds. Statistical evaluation yielded information regarding the pollutant constituents of wetfall and dryfall and the relationships of the different monitoring sites to each other. The following points summarize the finding of the Atmospheric Deposition Report.

1. Wetfall ammonia was found in similar quantities at each monitoring site. Likewise, dryfall ammonia was constant at each site. Wetfall values, when compared to dryfall, were much higher, possibly due to the highly water soluble, gaseous nature of ammonia. The pollutant seemed to occur in an area-wide pattern, with little effect from local (watershed specific) influence. The highest amounts of ammonia were measured during the summer months.
2. Total kjeldahl nitrogen (TKN) appeared in similar amounts at all monitoring sites, and in both wetfall and dryfall. Wetfall values correlated significantly at each site, indicating an area-wide pattern of TKN occurrence, while dryfall amounts appeared to show no relationship to each other. Summer wetfall values were slightly higher than other seasonal amounts. Linear correlations of other monitored nitrogenous pollutants with TKN values, strongly illustrated their native interrelationships.

3. The ammounts of nitrate-nitrite (NO_3/NO_2) measured at each of the CBD monitors were similar, but dryfall amounts in that watershed were higher than at the residential site. Automotive input of nitrogen oxides was thought to influence this difference. Microanalysis of high volume air sampler filters supported this theory. Wetfall amounts of the pollutant were higher than dryfall amounts, probably due to the gaseous nature of the pollutant. The appearance of NO_3/NO_2 was fairly consistent throughout the area during every season of the year.
4. Total phosphorus (TP) was detected in almost all dryfall samples, while it was measured in only 7% of the wetfall events. No differences were found between the two watersheds in their dryfall TP amounts. Streetside levels, however, were marginally higher than those at the Cherry Deck. The unpaved parking areas immediately adjacent to the monitoring sites are thought to provide this influence. Seasonal comparisons seemed to indicate a greater distribution of TP in the CBD over the RES watershed, although this was not supported statistically.
5. No differences were noted in copper amounts at any of the three monitoring sites between wet and dry deposition. Dryfall samples in the RES watershed, however, never contained detectable quantities of the metal. Linear comparisons of the dryfall copper values were significant within the CBD. No specific seasonal relationships were noted for wetfall copper.

6. Dryfall amounts of zinc were significantly higher in the CBD watershed than in the RES. Furthermore, levels at the Second Street site were higher than those at the Cherry Deck, indicating a probable influence from local traffic. Zinc was detected in every dryfall sample, while being measured in only 18% of the monthly rainfall composites. A strong linear correlation was indicated between lead and zinc deposition, again suggesting a traffic related input. Seasonal comparisons suggested the possibility of one biased sample from the Second Street dryfall monitor.

7. As was the case with zinc, lead was detected much more frequently in dryfall samples than in wet samples. No differences were established between dry and wet deposition because there were too few paired samples available for comparison. Streetside levels of the metal were significantly higher than amounts at either of the other sites. No correlation was found between the two CBD monitors. Seasonal comparisons displayed the predominance of dryfall lead amounts in the CBD over the residential watershed, and at the Second Street site over the Cherry Deck, particularly in the fall and winter. Lead levels appear to be strongly influenced by traffic.

8. Mercury was detected in relatively few samples, as compared to the other detected pollutants. It appeared more often in dryfall samples than in wetfall, and slightly more often in the CBD than the RES. Dry mercury values were higher at the Cherry Deck site than at the Second Street site, and were significant when correlated. Seasonal comparisons demonstrated the considerable disparity between the CBD and the RES levels.

9. When total pollutant weights were composited, only the Residential monitoring site indicated a significant difference in wet and dry loading, with wetfall pollutant content higher than dryfall. Wetfall loadings were comparable at all three monitoring sites, while dryfall displayed more variability. Wetfall volume at all three sites was also consistent. Seasonal distributions of total composite weights seemed to indicate a greater abundance of pollutants in the CBD than the RES in every part of the year. The streetside monitor appeared to be the most heavily loaded of the three sites.

10. Mean pH values were comparable at all three monitoring locations and individual rain event pH values correlated significantly. The mean pH levels of 3.74 to 3.82 were below the 5.6 level indicative of "pure" rainfall. Weighted averages, using rainfall volume, were not appreciably different than the unweighted means. No significance was found when wetfall sulfates and pH were correlated. Analysis of sulfate content was undertaken late in the project, resulting in only a few data points for comparison purposes.

11. Analysis of high volume air sampler filters indicated that traffic on unpaved and paved surfaces seemed to be the primary contributor of particles to suspended particulate concentrations. Large particle sizes suggested that emission sources of mineral materials were located within a few hundred feet of the sampling site. Mineral content and seasons of the year were related, with higher values occurring during dryer and hotter times of the year.

12. Wind roses indicated that in the few hours immediately preceding a storm event, winds are, in general, southerly, regardless of the time of year. On dry days, the wind was observed from numerous directions, and reflected historical measurements.

The above observations led to the conclusion that wetfall pollutant deposition is generally area wide in nature, i.e., for any given monthly wetfall, the amount of pollutant loading in each of the two investigated watersheds tends to be similar. Dryfall, however, appears to be influenced by local sources and may vary significantly within short distances. After pollutants are deposited on a street surface, they may be reintrained and redeposited, resulting in higher concentrations at closer streetside locations. Correlations of pH to measured pollutants were inconclusive, but observed pH values suggest an area of interest for future study.

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APPENDIX

The following two tables are comprised of data sets which were not available at the completion of the preliminary draft report. They are being included here, as an appendix, as they relate directly to the per event water quality data discussed in the water quality sections of the Winston-Salem/Forsyth County Urban Runoff Project final report.

Additionally, these data are being included in this format as an aid to other agencies participating in the National Urban Runoff Project whose data have been reported solely on a per event basis.

Table 1A

EVENT RANGES, MEANS AND STANDARD DEVIATIONS OF OBSERVED LOADING OF NUTRIENT CONSTITUENTS WETFALL SAMPLES (LBS/ACRE)

Pollutant	Station	Range of Observations	Mean	Std. Dev.	Number of Events With Detected Amounts*
NH_3	Deck	.0069 - .1833	.0456	.0341	83
	Street	.0052 - .2863	.0498	.0460	76
	Res	.0068 - .4104	.0496	.0610	53
TKN	Deck	.0081 - .2155	.0585	.0404	83
	Street	.0094 - .2136	.0609	.0459	76
	Res	.0068 - .2156	.0526	.0394	53
NO_3/NO_2	Deck	.0057 - .2186	.0534	.0360	83
	Street	.0051 - .2065	.0534	.0388	76
	Res	.0056 - .2012	.0510	.0353	53
TP	Deck	.0008 - .0176	.0047	.0039	83
	Street	.0001 - .0915	.0066	.0115	75
	Res	.0008 - .0237	.0052	.0050	53

*NOTE: Central business district data (Deck and Street) are derived from twenty-five months of sampling, while residential (Res) data represent fourteen months of sampling.

Table [illegible]A
EVENT RANGES, MEANS AND STANDARD DEVIATIONS OF OBSERVED LOADINGS OF METAL CONSTITUENTS
WETFALL SAMPLES (LBS/ACRE)

Pollutant	Station	Range of Observations	Mean	Std. Dev.	Number of Events With Detected Amounts*
Cu	Deck	.0005 - .0154	.0042	.0035	76
	Street	.0001 - .0142	.0043	.0032	69
	Res	.0006 - .0144	.0041	.0030	40
Zn	Deck	.0008 - .0294	.0054	.0047	75
	Street	.0007 - .2872	.0095	.0342	69
	Res	.0007 - .0180	.0052	.0037	40
Pb	Deck	.0003 - .0723	.0110	.0107	76
	Street	.0014 - .0712	.0111	.0109	69
	Res	.0015 - .0588	.0109	.0107	40
Hg	Deck	$.9\times10^{-5}$ - 81.7×10^{-5}	7.5×10^{-5}	11.6×10^{-5}	55
	Street	$.7\times10^{-5}$ - 42.3×10^{-5}	7.3×10^{-5}	7.2×10^{-5}	51
	Res	$.5\times10^{-5}$ - 513.0×10^{-5}	22.7×10^{-5}	92.7×10^{-5}	30

*NOTE: Central business district data (Deck and Street) are derived from twenty-five months of sampling, while residential (Res) data represent fourteen months of sampling.